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## PERIODIC EXAMINATION OF SEWAGE FOR THE VIRUS OF POLIO-MYELITIS\*

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During epidemics of poliomyelitis in 1939, the virus was detected in sewage collected in Charleston, South Carolina (1-3) and Detroit, Michigan (2). All told in North America 6 positive tests were obtained with 4 samples of sewage. These were among a total of 30 specimens examined which, in addition to representing the cities mentioned above, included samples from Windsor, Ontario, Buffalo, New York, and from a rural area in Michigan. The series included 22 tests on 11 post-epidemic specimens from 4 large cities and the results of these tests were negative (2). In Sweden during an epidemic in Stockholm a positive result was obtained by Kling in October, 1939 (4). These positive findings probably have epidemiological significance but as yet they throw no crucial light on the pathogenesis of poliomyelitis and in order to understand them better it is still a matter of importance to know more about normal conditions in respect to virus in sewage. Accordingly, data on sewage collected routinely over a number of months is presented in the following report. It describes periodic sampling in New Haven, Connecticut, and in New York, New York, largely during non-epidemic periods.

### Methods

Samples of raw, unchlorinated sewage were collected monthly from New Haven, Connecticut and from New York, New York, from April, 1940, to June, 1941. The sites of collection in New Haven were (a) a trap in the Isolation Pavilion, a 60-bed unit of the New Haven Hospital and (b) a comminuting chamber of the City Point Sewage Disposal Plant. In New York the collections were made at the Manhattan Grit Chamber at 110th Street and East River Drive.<sup>1</sup> There is an average daily

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<sup>1</sup> For the privilege of examining samples of sewage from New York and for access to the daily analyses of it we are indebted to Mr. W. Donaldson, Director, Bureau of Sewage Disposal. For the privilege of examining the sewage of the City Point Disposal Plant, New Haven, Connecticut we are indebted to Mr. W. Vincent Barry, Acting Director of Public Works and Dr. J. L. Linde, Health Officer, New Haven, Connecticut.

flow of about 14 million gallons of sewage through the New Haven City Point Plant which serves a population of 119,800 and an area of 5500 acres in New Haven and its suburb Hamden. The Manhattan Grit Chamber has a daily average flow of 88 million gallons and it serves a population of 623,000 and an area of 3,253 acres in Manhattan.

The technique was based on that used successfully in Charleston and Detroit (1-3). 4 liters of sewage were collected between 8 and 10 a.m., placed in the refrigerator to sediment for 3 to 6 hours when 700 cc. of the middle layer were siphoned into a 1 quart bottle, treated with 105 cc. of ether, corked, and refrigerated overnight. The next morning 20 cc. of etherized sewage were inoculated intraabdominally into a rhesus monkey (*M. mulatta*) and 200 to 400 cc. were concentrated to a volume of 30 to 50 cc. with  $(\text{NH}_4)_2\text{SO}_4$  by Gard's method (3) and on the next day the concentrate was inoculated intraabdominally into another rhesus monkey. After 12 months of sampling, inoculations of unconcentrated sewage were discontinued and tests were limited to the use of concentrated inocula. Criteria for the identification of the virus of poliomyelitis were the same as those used previously (2) and consisted in (a) the reproduction of infectious myelitis in the monkey with (b) characteristic histological lesions in upper and lower levels of the spinal cord and (c) passage to another monkey. Also tests in small animals were used. The criteria for a negative test were that the monkey survived for 4 weeks of observation either remaining well, or if an irregular temperature curve or other signs appeared, that the animal revealed no histological lesions in the parenchyma of its brain stem or cord on autopsy. Among these animals special attention was given to the presence or absence of histological evidence of choroidal or meningeal reaction.

If the monkey inoculated with the concentrate was lost before the expiration of 4 weeks the test was considered incomplete and is recorded in Table I with a zero sign unless a repeated specimen was tested satisfactorily that month.

## RESULTS

The results are presented in Table I which reveals that of 45 monthly tests for the virus of poliomyelitis 36 were completed and of these 35 were negative and 1 was positive.<sup>2</sup>

The details of the positive test were as follows:

September 19th, the specimen was collected at the Manhattan Grit Chamber, September 21st, the inoculum of 30 cc. (the concentrate from 400 cc. of etherized sewage) was injected intraabdominally into monkey 16-24 which remained well until September 30th, when it had fever. October 1st, it was tremulous and both legs were paralyzed, October 2nd, it was prostrate and was killed with ether. Passage with glycerolated spinal cord was successful in *M. mulatta* and the histological lesions were typical. Some further tests were made and on intracutaneous inoculation the

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<sup>2</sup> This positive test was mentioned recently in a footnote, Paul, J. R., and Trask, J. D., *J. Am. Med. Assn.*, 1941, **116**, 493.

strain was non infective in 1 *M. mulatta*. On intracerebral inoculation in small animals with the strain, 2 guinea pigs remained well and 1 of 6 Swiss mice died. The mouse died on the 14th day but had no histological signs in brain, cord, or meninges, 1 of the other mice had slight microscopic evidence of a low grade encephalitis which seemed to be non acute. There was no meningitis, encephalitis, or myelitis in the guinea pigs. Serial passage in small animals was not tried.

TABLE I

*Tests for the Virus of Poliomyelitis in Sewage in Relation to Cases Reported in New York N. Y., and in New Haven Conn. — April 1940 to June, 1941*

Month	New York, N. Y.			New Haven, Conn.			
	Cases of poliomyelitis reported		Tests for virus at grit chamber	Cases of poliomyelitis reported		Tests for virus in sewage	
	In city	On sewer lines		In city	In hospital	City Point disposal plant	Hospital
1940							
Apr	1	None	—	None	None	0	—
May	None	"	0	"	"	—	—*
June	"	"	0	"	"	—	0
July	7	4	—	"	"	—	—
Aug	16	3	—	"	3	—	—
Sept	25	4	+	"	2	0	0
Oct.	14	None	—	"	2	—	—
Nov	3	"	—	"	1	—	0
Dec.	1	"	—	"	1	—	—
1941							
Jan.	None	"	—*	"	None	0	—
Feb	2	"	—	"	"	—	—
Mar	None	"	—	"	"	—	—
Apr	"	"	—	"	"	—*	—
May	1	"	—	"	"	—	0
June	None	"	—	1	1	—	—

+, positive for poliomyelitis virus, — negative 0 not completed

\* Mononuclear meningitis without lesions in cord or brain stem.

The other monkey (No. 16-23) used in the routine test of the sample of September 19, from New York received only 20 cc. of unconcentrated sewage and remained well during its period of observation. At autopsy no lesions were seen in its cord on microscopic examination. This furnishes corroborative evidence that Gard's (3) method of concentration is valuable.

Previously the stability of the virus in sewage kept in the refrigerator had been slight (3). In order to make another test of this property the process of concentration was repeated October 7 on 400 cc. of the original specimen which had been kept in the refrigerator since September 19. The result was negative.

Tests with subsequent samplings from the Manhattan Grit Chamber of which



there were 2 in October, 1940, and which up to the present writing are being continued at monthly intervals, have been negative.<sup>3</sup>

Among the 35 tests which appear in Table I as negative for poliomyelitis there were 3 (1940, May, 1941, January and April) in which microscopic examination at the close of the experiments revealed a mild meningitis or chorioiditis without lesions in parenchyma of brain stem or cord. The 3 monkeys had fever and agitation during the 2nd and 3rd weeks but no weakness or other signs of myelitis were observed. Passage of these 3 cords to monkeys or small animals has not been tried.

It seems pertinent to state that the inocula used for 2 of these 3 animals had been prepared by Gard's method and that in the single instance (January, 1941) when a meningeal reaction was observed in a monkey following the injection of unconcentrated sewage its mate which received the concentrate was lost on the 2nd day. A subsequent sample that month evoked no reaction, with or without concentration.

The results for September and October, 1940, and for January and May, 1941, represent repetitive sampling, generally because of the premature loss of the inoculated monkeys. In the entire series 87 monkeys were used. Of these, 11 were lost intercurrently: 8 following concentrated and 3 following unconcentrated inocula, 3 died in the first 3 days with intestinal distension and fatty liver as chief findings, 1 died on the 4th day with purulent peritonitis, and 7 died on the 7th to 25th day also with purulent peritonitis.

Besides the results of the tests, it may also be seen from Table I that there were remarkably few cases of poliomyelitis reported during the period of 15 months covered by the experiments. Actually there was only one reported from New Haven although a few patients from the nearby cities of Waterbury, Cheshire, and Naugatuck were in the Isolation Pavilion of the New Haven Hospital at various times from August to December. Accordingly, in respect to New Haven, the period under study may be considered essentially as inter-

<sup>3</sup> The serial monthly examinations have now been carried through October, 1941, and only one further significant result has been obtained. This was with sewage collected from the Manhattan Grit Chamber, October 14. The monkey inoculated intraperitoneally with the  $(\text{NH}_4)_2\text{SO}_4$  concentrate from 400 cc of etherized sewage, remained well until the 10th day, then it developed fever. On the 12th day, tremor and ataxia were observed and on the 15th paralysis of the legs. On histological examination the lesions were characteristic and well marked throughout the spinal cord. Thus the picture was typical of experimental poliomyelitis but successful passages are necessary before the criteria of a positive result have been met. Attempts at these passages are now in progress. So far guinea pigs and Swiss mice inoculated intracerebrally with the infected cord have remained well.

During the summer and fall of 1941 there was a distinct increase in cases of poliomyelitis reported from Manhattan in the area served by the Grit Chamber.

epidemic. In New York City there was a slight but progressive increase in cases reported<sup>4</sup> in 1940 during July and August, to reach a peak in September with a gradual decline subsequently to none for January, 1941. Some of the cases recorded for July, August, and September (4, 3, and 4 respectively) were from the region served by the sewer being sampled. Nine of these 11 cases were from a relatively small area between 160th and 180th Streets near Audubon Avenue and they appear as a small focus in Fig. 1.

An incidental finding, concerning the detection of tubercle bacilli in sewage, was made during the study. Certain monkeys, inoculated intraabdominally with the routine dose of 20 cc. of etherized unconcentrated sewage, contracted an unusual form of peritoneal tuberculosis whereby, 6 to 12 weeks after inoculation, the omentum and visceral peritoneum were found studded with tubercles of fairly uniform size while lungs, pulmonary nodes, liver, spleen, and kidney

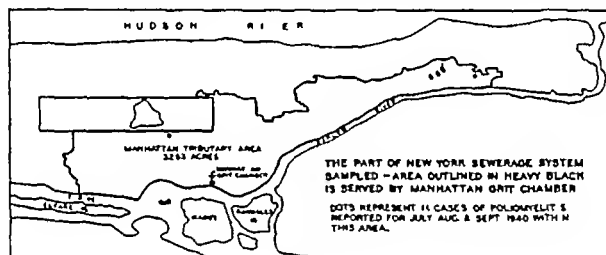


FIG. 1

were relatively free. This reaction was not encountered after the sewage had been subjected to concentration but after the inoculation of 20 cc. unconcentrated Manhattan sewage this form of tuberculous peritonitis was common. In fact, in monkeys observed for 6 weeks or more, it was seen in all of 7 monkeys so inoculated. From one of them a strain of tubercle bacillus was recovered which was identified as of human type by its growth in the presence of glycerol and its pathogenicity for guinea pigs and relative lack of pathogenicity for rabbits.

#### DISCUSSION AND SUMMARY

This communication records an additional example of the detection of the virus of poliomyelitis in urban sewage. If we assume that the virus detected had a direct human origin and that this is represented, even remotely in Fig. 1,

<sup>4</sup> For help at the inception of the study and for subsequent epidemiological data we are indebted to Dr. John L. Rice, Commissioner of Health, and to Dr. Samuel Frant, Director, Bureau of Preventable Disease, New York City.

then either the heaviness of the contamination of the sewage, or the amount of dilution which the virus tolerated, are truly amazing

The positive result and its relation to cases of poliomyelitis reported add little to our knowledge of the *pathogenesis* of poliomyelitis, but at least the data are of some special epidemiological significance. The nature of this is not yet obvious, chiefly, perhaps, because it is not yet known whether the increase of cases precedes or follows an increase in the hypothetical basal level of the virus in sewage. However, as far as the data go they do not suggest that the virus is more or less evenly distributed throughout the year and that epidemics of paralysis are conditioned chiefly by variations in susceptibility which is postulated by Aycock's (5) hypothesis of autarcesis in poliomyelitis. However, it seems likely that the solution of this problem must await the development of better methods for it must be admitted that our present ones are crude

Incidentally, the positive result recorded herein helps to confirm the value of Gard's method of concentration (3) which not only lead to the detection of the virus but also decreased the hazard of tuberculous peritonitis in the experimental animals in the present series. It is also suggested that the monkey may be a useful animal for the detection of tubercle bacilli in sewage. This raises the issue of how it was possible to inoculate monkeys with as much sewage as was done without detecting more varieties of familiar pathogenic agents. There are some obvious reasons for this. One is that by neglecting to try passage we may have missed a "meningitic virus" in the 3 monkeys which had fever and histological evidence of mononuclear meningitis. Another reason is that our methods were highly selective because systematic observations were limited to body temperature, to general features, to the function of motion, and to the histology of the cord and brain stem. Thus pathogenic bacteria, measles, mumps, etc., could have infected our monkeys without our knowing it.

#### CONCLUSIONS

From a series of tests covering 15 months, another instance is recorded of the detection of the virus of poliomyelitis in urban sewage.

It has not yet been possible to detect the virus of poliomyelitis in sewage during non-epidemic periods.

It is likely that the periodic sampling of sewage for pathogenic viruses or bacteria may be a method of epidemiological value.

#### BIBLIOGRAPHY

- 1 Paul, J. R., Trash, J. D., and Culotta, C. S., *Science*, 1939, 90, 258
- 2 Paul, J. R., Trash, J. D., and Gard, S., *J. Exp. Med.*, 1940, 71, 765
- 3 Gard, S., *J. Exp. Med.*, 1940, 71, 779
- 4 Kling, C., cited by Levaditi, *Bull. Acad. m d.*, Paris, 1940, 123, series 5, 335
- 5 Aycock, W. L., *J. Prevent. Med.*, 1929, 3, 245

# THE ENDURING PARTNERSHIP OF A NEOPLASTIC VIRUS AND CARCINOMA CELLS\*

## CONTINUED INCREASE OF VIRUS IN THE V2 CARCINOMA DURING PROPAGATION IN VIRUS-IMMUNE HOSTS

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The rabbit papilloma virus (Shope) gives rise under natural conditions to horny cutaneous growths in wild cottontails (1), and to papillomas of similar sort when inoculated into domestic rabbits. The growths of both species may become malignant after a while through alterations in the virus-infected cells (2), but the virus has never been recovered from the cancers, nor can it be got ordinarily from many of the papillomas induced with it in domestic rabbits. Yet it persists in masked or altered form in the cancers as well as in the papillomas, as serological tests have proved: an antibody directed specifically against the virus appears in the blood of rabbits carrying the growths, and its titer rises as the tumors enlarge (3).

One of the cancers originating in a virus-induced papilloma and transplanted successfully—the V2 carcinoma—has now been carried through 21 tumor generations in the course of more than three years. It grows rapidly in a considerable proportion of hosts and often metastasizes. Tests have been made for the specific antiviral antibody in the blood of rabbits of every tumor generation,—more than a hundred animals in all. This has never been found in the blood of normal control animals, nor in noteworthy titer in rabbits implanted with the tumor but negative, but it has regularly appeared in the blood of rabbits in which the V2 carcinoma has grown progressively, attaining a titer as high as that in animals which have long carried large papillomas, or even higher. The strength of the antibody has been as great in recent tumor generations as in the early ones (3).

The persistence of virus in the transplanted V2 carcinoma does not seem remarkable when the fact is recalled that wholly extraneous, parasitic viruses—vaccinia, virus III, yellow fever, infectious ectromelia, to name but a few—can ride along as passengers in other transplanted tumors (4), as can also spirochetes, pleuropneumonia like microorganisms, and various other bacteria (5).

\* Read in brief at the meetings of the American Association for Cancer Research, Chicago April 15 1941, abstract in *Cancer Research*, 1941, 1, 730.

But the fact is now becoming manifest that passenger viruses may disappear spontaneously from the tumors they ride upon, while some have been got rid of by transplanting the growth to hosts immune to the virus. Rivers and Pearce observed long ago that virus III could vanish from the Brown-Pearce tumor as casually as it had appeared, and Andrewes recently noted that a rabbit sarcoma—the RSI—became free of passenger virus III when transplanted through a rabbit previously immunized against it (6). He also found that the Brown-Pearce carcinoma could be rid of virus III by propagation in two successive virus III-immune rabbits, and from vaccine virus by passage through a single animal immune to it. Identical results were got with the same materials by Pearce (7).

These findings bring up the possibility that the V2 carcinoma can be freed of associated virus by growing it in a succession of hosts immunized against it. The work here reported was done to learn whether such is the case. The general plan was to propagate the V2 carcinoma in five successive groups of animals all hyperimmunized beforehand against the papilloma virus, and then to determine whether, upon return to normal hosts, the growth would elicit antiviral antibodies in the same high titer as before.

### Methods

To *hyperimmunize* the rabbits to which the tumor was to be transferred, four “pancake” papillomas were produced on the flanks of the animals by rubbing a potent virus suspension into areas of skin about  $6 \times 8$  cm. which had been freshly scarified with sandpaper. Confluent papillomatosis usually resulted after an incubation period of about 10 days, and the growths rapidly enlarged into characteristic horny masses, these often rising 2 cm. or more above the skin level. Growth of this sort usually elicit antiviral antibody in considerable titer, and this can be greatly increased by repeated injections of large quantities of virus intraperitoneally, as previous work has shown (8). Accordingly, 10 days to 3 weeks after the scarifications, 10 cc. of a 1:20 Berkefeld V filtrate of wild rabbit papillomas which were known to contain virus in quantity was injected intraperitoneally into each animal. The intraperitoneal injections were repeated 7 days later, and after a further interval of 7 to 10 days the rabbits were bled from an ear vein and the sera tested. At this time they were implanted with the tumor.

Much use was made of the *complement fixation test* to titer the antiviral antibody. Previous work had demonstrated its specificity and reliability as a gauge of immunity to the papilloma virus (9). The test was carried out as previously described (9), using 2 units of complement (titrated immediately beforehand) and 2 hours at room temperature for fixation. Antigen from two sources was used—the natural papillomas of W. R. (wild cottontail rabbit) 1-28, and the pooled natural papillomas of five cottontails, P. Both materials yielded much virus. A 1:120 saline extract of the glycerolated papillomas from both sources had been found in previous experiments to provide an optimal quantity of antigen (virus), and hence this dilution was uniformly used. Mention need hardly be made here of the fact that the complement

fixation reaction provides a comparative, not an absolute, measure of the titer of antiviral antibody. Sometimes the results with a single serum varied by as much as a twofold dilution in different tests but the variation was never greater. A serum can be considered very potent if, after dilution to 1:24 or more it contains enough antibody to fix completely 2 units of complement in mixture with an optimal dose of antigen. Such a serum is capable of neutralizing many thousand infectious doses of virus, and an animal yielding it is usually resistant to infection with the virus as previous studies have shown (8). In the present work the antibody titer has been expressed in terms of the highest dilution of serum that gave complete or almost complete fixation in the standard test. Dilutions beyond 1:128 were not tested, for when fixation is complete at this dilution the quantity of antibody is great, and hyperimmunization may be deemed maximal.

The neutralization test for antiviral antibody was also used. It was applied as previously described (14-9).

The virus suspensions for primary inoculation and subsequent hyperimmunization were made by grinding the glycerolated natural papillomas of cottontails in a mortar with sand and suspending the ground paste in physiological saline, usually 1:10 to 1:20 (10 per cent and 5 per cent extracts). The suspension was then spun clear and sometimes passed through a Berkefeld V filter in addition. To spread the conditions, five different virus materials were used, all highly pathogenic. Always a different material was injected intraperitoneally from that with which the rabbit had been cutaneously inoculated.

Normal adult gray brown rabbits (agouti hybrids) were used throughout, males and females indiscriminately. All weighed 2.5 kilos or more.

Transplantation of the tumor was effected by a method somewhat different from that used in the previous work, in order to provide conditions under which the antiviral antibody might have better opportunity to act. A fine suspension of carcinoma tissue was used instead of hashed pieces and the tissue was kept moist and finally suspended in Tyrode to which immune serum had been added. The tumors were procured with aseptic precautions and the "healthiest" portions carefully selected from nodules taken from at least two different situations in each animal. By means of a small pestle the tumor tissue was pressed through a 40-mesh monel metal sieve, with the addition of Tyrode immune serum (usually 10 parts of Tyrode to one of the animal's own serum), the result being a turbid finely particulate suspension. 1 cc. portions of the suspension were then implanted into the leg muscles of the new hosts at six situations—both forelegs and the anterior and posterior muscles of both thighs. The fastest growing tumors were sometimes selected for transplantation and again slower-growing ones were utilized to spread the conditions.

#### *Successive Transplantations of the V2 Carcinoma in Virus Immune Rabbits*

The course of the transplantations is summarized in Chart 1.

*The Starting Tumor*—The history of the V2 carcinoma has already been given in detail from its inception to the 13th serial transplantation when the present experiments were begun (3). To procure material for them a 12th generation tumor was implanted into the muscles of the upper forelegs and anterior and posterior thighs—

# Passage of the V2 Carcinoma through Immunized Rabbits

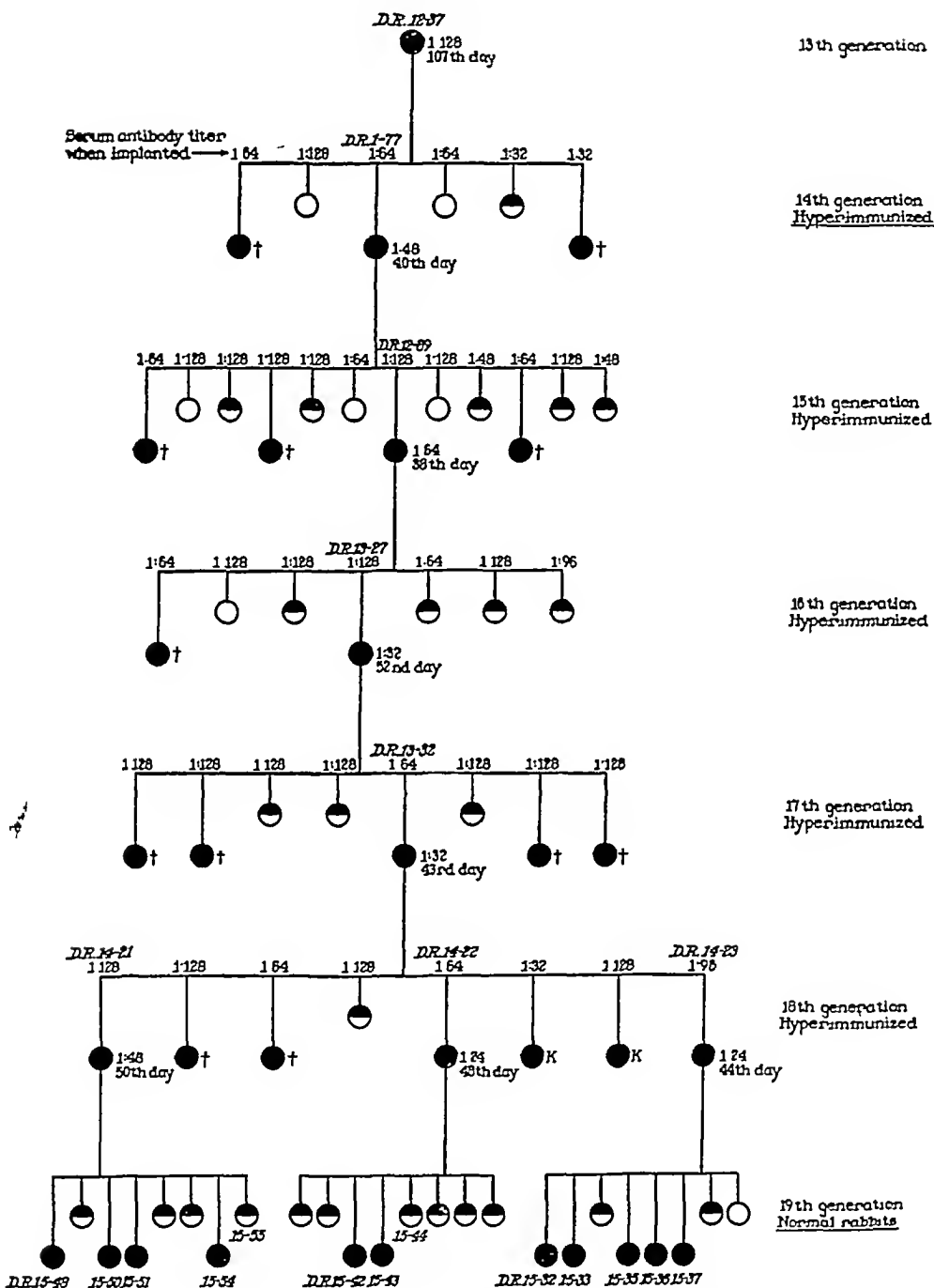


CHART 1 A summary of the transplantations. The black circles denote individual rabbits in which tumors grew progressively, half-white ones, animals in which regression occurred, white ones, rabbits in which no palpable nodules developed. The animals remain anonymous except for those providing material for transfer and the ones bled for serum in the final generation—see Table III. D R. = domestic rabbit, K = killed, † = died from tumor. For further explanation see text.

the usual situations—in D. R. (domestic rabbit) 12-37, amongst others. Palpable nodules were present in three of the situations when the animal was examined on the 17th day, and in two more later on. By the 42nd day the five nodules range from 1.2 to 3.2 cm. in size. All enlarged greatly in the ensuing 8 weeks, at length reaching diameters of 7.5 to 10.0 cm., the animal during this time becoming thin and weak. The antiviral antibody titer of its blood as determined by complement fixation was found to be 1:128 on the 107th day, when it was killed and the tumors procured for transplantation. They were huge cysts of the sort already described (3), filled with thick, glairy, mucoid fluid in which floated yellowish gouts of necrotic material, and with walls 1 to 3 mm. thick, composed of pale-pink, close-texture tumor tissue. The healthiest portions of the neoplastic tissue were pressed through the monel metal sieve and suspended in a mixture of Tyrode and the animal's own serum (proportion 20:1).

*First Transfer to Hyperimmunized Rabbits, 14th Generation*—The tumor suspension of D. R. 12-37, described above, was implanted into the six muscle situations of six hyperimmunized rabbits. At the time all bore four large confluent papillomatous masses, each about 6 × 8 cm. across and raised 0.4 to 0.8 cm., as result of inoculation 30 days before with W. R. (wild rabbit) 1-72 virus, 1:20. Intraperitoneal injections of 10 cc. of virus filtrate W. R. 1-68, 1:20, had been made on the 14th and 21st days and the serum antibody titers now ranged from 1:32 to 1:128. Progressively enlarging carcinomas developed in three of the implanted animals; early regression took place in one and no palpable tumors developed in the other two (see chart).

*Further Transfers in Hyperimmunized Animals*—By the 40th day after implantation the six growths of D. R. 1-77 (14th generation—hyperimmunized) had become cysts of characteristic sort, varying from 3.5 to 7.5 cm. in diameter. The rabbit was bled and the complement fixation titer found to be 1:48. It was killed and a suspension made by sieving the healthy portions of its tumors into Tyrode plus the animal's own serum (10:1). The suspension was then implanted into the leg muscles of twelve hyperimmunized rabbits (15th generation) all of which carried large confluent papillomas resulting from the inoculation of W. R. 1-28 virus, 1:10, 24 days before. The animals had been injected intraperitoneally with 10 cc. of virus filtrate W. R. 16-96 1:10, on the 12th day, and with 10 cc. of virus filtrate W. R. 1-68 1:10, on the 18th day, and they now had serum antibody titers ranging from 1:48 to 1:128. The implantations resulted in progressively enlarging tumors in four rabbits, regressing ones in five and no palpable growths in three.

The details of the remaining transfers into hyperimmunized animals need not be given, for they do not differ significantly from those just furnished.

*The Eventual Transfer to Normal Animals*—Tumors grew progressively in seven of the eight implanted rabbits of the 18th generation—the fifth hyperimmunized group. The growths of three (D. R. 14-21, 14-22, and 14-23) were implanted in normal rabbits as indicated in the chart, each material into a different group of eight animals. For the final transfers sieved suspensions were made as usual, but plain Tyrode was used instead of Tyrode plus host serum since it was deemed advisable to avoid the passive transfer of antibody as possibly affecting the outcome of tests of the blood of the new hosts. As the chart shows, the implantations from D. R. 14-21 grew progressively in half of the eight normal rabbits; regressing in the others. The D. R. 14-22 tumors gave progressively enlarging growths in two instances, regressing



ones in four, and no palpable nodules in two, while the D. R. 14-23 material provided progressively enlarging tumors in five rabbits, regressing growths in two, the eighth individual remaining negative. Details of the serum tests will be given further on

### *General Findings*

When viewed in the large, the results of the transfers, as summarized in Chart 1, leave no doubt that the V2 carcinoma can be readily propagated in animals hyperimmunized against the papilloma virus. It was maintained in this way in five successive tumor generations during nearly 8 months in all. Implantation of the growth into animals having very high titers of antiviral antibody often resulted in tumors that appeared promptly and grew progressively, frequently killing the hosts, but the outcome of the implantations varied much from one generation to the next and from individual to individual in the same generation. The question arises, therefore, whether the tumor grew as well in virus-immune animals as in comparable normal ones. Chart 1 goes far towards answering the question. The cancer flourished in many of the hyperimmunized hosts, its course comparing favorably with that in the tumor generations before hyperimmunization was undertaken (3), and when it was eventually returned to normal animals the number of "takes" and of progressively enlarging and regressing growths, though differing somewhat from one group of hosts to another, was on the whole no different from that obtaining in the last generation of hyperimmunized rabbits. To safeguard the tumor it had been propagated in normal animals as well as in the hyperimmunized ones throughout the period of experimentation. Hence the material for an additional comparison is available (Table I).

The passages in normal rabbits were made during the same months as those through the hyperimmunized but were not done simultaneously, and the materials used, though of the same tumor generations, came of necessity from different groups of animals. Furthermore, hashed tissue was implanted into the new normal hosts, and sieved suspensions into the hyperimmunized, and the animals of both groups were market bought, which is to say that none was pure bred. Even so, it becomes evident from Table I that the outcome of implantations of the V2 carcinoma, though varying somewhat as in the case of other propagated neoplasms, was not significantly different in the hyperimmunized and the normal rabbits. "Takes" developed in two-thirds or more of the implanted rabbits in all of the groups (Table I). Progressively enlarging tumors developed in from 28 to 87 per cent of the hyperimmunized animals and in from 17 to 54 per cent of the normals, while regression took place in from 13 to 56 per cent of the hyperimmunized rabbits and in from 33 to 83 per cent of the controls.

From the findings just given it is manifest that the V2 carcinoma grew as well in the hyperimmunized rabbits as in the normals, and this fact makes it seem altogether unlikely that the antibody titer of the hyperimmune rabbits at the time of implantation would have any influence on the outcome. That it had none can readily be seen from an inspection of Chart 1. In the 14th gen-

eration, for example, tumors enlarged progressively in three animals having antibody titers when implanted of 1:64, 1:64, and 1:32, respectively, no palpable nodules appeared in a rabbit with antibody titer of 1:64, and regression of the growths took place in two animals with titers of 1:32 and 1:128, respectively. So too in the 15th and the succeeding generations the tumors grew, or failed to develop, or regressed irrespective of the antibody titer at time of implantation.

TABLE I

*Outcome of Implantations of the V2 Carcinoma in Rabbits Hyperimmunized against the Papilloma Virus and in Normals*

Generation	Number of rabbits implanted		Number developing palpable nodules		Number in which tumors grew progressively		Number in which tumors regressed	
	Hyperimmunized	Normal	Hyperimmunized	Normal	Hyperimmunized	Normal	Hyperimmunized	Normal
14th	6	11	4 (67%)	8 (73%)	3 (50%)	6 (54%)	1 (17%)	3 (33%)
15th	12	9	9 (75%)	8 (89%)	4 (33%)	3 (33%)	5 (42%)	5 (56%)
16th	7	12	6 (84%)	11 (92%)	2 (28%)	2 (17%)	4 (56%)	9 (75%)
17th	8	12	8 (100%)	12 (100%)	5 (62%)	2 (17%)	3 (38%)	10 (83%)
18th	8	8	8 (100%)	8 (100%)	7 (87%)	4 (50%)	1 (13%)	4 (50%)

Hybrid agouti rabbits procured from various dealers were used throughout.

The transplantations in corresponding hyperimmunized and normal generations were made during the same months but not simultaneously.

No distinction is made in the table between the animals in which regression was complete and the occasional ones in which it was partial and transitory, i.e., individuals in which all of the tumors dwindled for a time and some disappeared but one or more later enlarged.

Attention may be called in passing to the fact that the antibody titers of the hyperimmunized rabbits that provided tumors for transplantation were lower when the animals were killed than at time of the implantations 40 to 52 days before (Chart 1). The finding was not unexpected. For the high titers resulting from the injections of large quantities of virus intraperitoneally are not maintained, as previous experience had shown, and the antibody response was presumably at or near its height at the time the implantations were made. In many unimplanted rabbits immunized in other experiments the antibody titers fell during the 6 to 8 weeks following the intraperitoneal injections to less than one-half the maximum. Manifestly the virus present in the large papillomas growing on the bellies of the rabbits of the present experiments and in the V2 carcinomas proliferating in their leg muscles failed to keep the antibody

titer at its highest level. Such findings will not seem strange to students of the infectious diseases. Two possible reasons for them may be mentioned in the present case. The papillomas of domestic rabbits provide in general comparatively little antigenic stimulus, eliciting much lower titers of antiviral antibody than do growths of comparable size and duration in cottontails (9), and the V2 carcinoma, which eventually elicits very high titers of the antiviral antibody, does so only after the tumors have become large and cystic and have persisted for many weeks, as observations made recently with the collaboration of Dr. William F. Friedewald attest.

It is of interest to compare the course of the implanted V2 carcinomas with that of the cutaneous papillomas present on the same animal, for the reason that their relation to the host is very different. The cells of the V2 carcinoma come from another animal—the one in which this tumor first arose—whereas those of the papilloma are the animal's own, now infected with virus. Regression of the V2 carcinoma, like that of other transplanted cancers, would appear to be consequent upon an induced general resistance, directed against the foreign cells (10), whereas regression of the papilloma involves a resistance which is directed against such of the animal's own cells as have been rendered neoplastic by the virus (11). In neither case does the antiviral antibody have any influence on the fate of the tumor. Growths of both sorts often dwindle away in rabbits having little or no antiviral antibody in their blood, and they frequently grow progressively in other animals having high serum antibody titers. Can it be that regression of the V2 carcinoma and that of the papilloma depend upon the same mechanism?

A summary is given in Table II of the course of the papillomas and carcinomas in the 41 hyperimmunized rabbits of Chart 1. The papillomas grew progressively in all of the rabbits except two, whereas in six rabbits no carcinomas appeared and in fourteen others they regressed after having attained a diameter of 1 cm. or more by the 16th day after implantation. In twelve of them the nodules had regressed completely by the 40th day or shortly thereafter, in the other two regression was partial and transitory, with dwindling of the nodules between the 16th and 30th days, complete disappearance of several of them, and later enlargement of one or two.

The V2 carcinoma grew progressively in the one rabbit in which the papillomas regressed entirely. This animal (D. R. 12-83, 15th generation—hyperimmunized) developed only scattered discrete papillomas as result of the inoculation of the highly pathogenic W. R. 1-28 virus, 1:10, and these attained a height of 1 to 2 mm. on the 25th day, but had all regressed completely by the 38th day. The V2 carcinomas, implanted on the 25th day after virus inoculation, grew vigorously and progressively from the start at every situation, becoming 1.5 to 2.4 cm. in diameter by the 38th day, that is to say, during the period when the surface papillomas were regressing. They continued to enlarge, formed huge cysts 4.0 to 6.0 cm. across, and brought about the animal's death on the 88th day (63rd day after the implantations).

From the data just given (Table II) it becomes evident that virus-induced papillomas of autochthonous origin and V2 carcinomas resulting from transplantation may grow or regress independently of one another in the same host.

The findings do not allow a definite conclusion as to whether regression of the two types of growths is brought about by similar mechanisms, but they provide a sound basis for doubting that the mechanism is identical in the two cases. Local conditions and other factors as well have an important influence upon the course of virus-induced papillomas (11), and similar influences may be responsible for the highly various outcome of implantations with the V2 carcinoma.

The passage of the V2 carcinoma through the hyperimmunized animals did not result in any perceivable alteration in the neoplasm. Autopsies were done as routine on all animals dying from the tumor, and representative blocks were taken for microscopic study. No differences could be made out between the growths in the hyperimmunized rabbits and those in the normals.

TABLE II

*Fate of Autochthonous Virus Induced Papillomas and Transplanted V2 Carcinomas in the Hyperimmunized Rabbits of Chart 1*

	Number of rabbits
Papillomas and carcinomas grew progressively	20
Papillomas grew progressively—carcinomas failed to "take"	6
Papillomas grew progressively—carcinomas regressed	13*
Papillomas dwindled (partial regression) and carcinomas regressed completely	1
Papillomas regressed completely and carcinomas grew progressively	1
Total	41

\* Partial regression in two

### *Tests for Presence of Virus*

To determine whether the virus had persisted in the V2 carcinoma during its transfer serially through hyperimmunized animals, the growths of three rabbits of the 18th generation (hyperimmunized) were transplanted into as many groups of normals (Chart 1). Later on tests were made for the antiviral antibody in the blood of the rabbits in which the tumors had grown progressively.

Table III summarizes the results of the serum tests. It will be seen that five of the rabbits with carcinomas derived from D. R. 14-23 all had huge growths when bled on the 61st day following implantation. Their sera contained much antiviral antibody as manifested both by their capacity to react with the virus in the complement fixation test and by their ability to neutralize a potent suspension of it.<sup>1</sup> The tumors grew progressively in only two of the rabbits implanted with the growths of D. R. 14-22 and in only four of those implanted with the growths of D. R. 14-21. The antiviral antibody was present in quantity in the sera of all these, as the table shows. These sera

<sup>1</sup> The fact is conspicuous that the sera failed to neutralize the virus completely though many had high titers of antiviral antibody as determined by complement fixation. The phenomenon has already been discussed in relation to the limitations of the neutralization test as a gauge of antibody titer (12).

*Tests for Antitumor Antibody*      *blood of Rabbits Carrying V2 Carcinomas*

19th Tumor Generation    Growth Implanted in Normal Animals after 5 Serial Transfers in Virus-Immune Rabbits

Source of serum		Im planted	Complement fixation tests†										Neutralization tests Papillomas due to mixtures of serum and virus†																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
Normal rabbits implanted with V2 carcinoma	From immune rabbit		No	days	Diameter of growths (six situations)	Serum dilution						19th day				43rd day																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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D R 11-23					8-12-11-14-8-12	++	++	++	++	++	++	++	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0</

† 2 units of complement in all tubes

Antigen, P, 1 120

None of the sera was anticomplementary when tested concurrently in double volume, nor was the antigen

† Equal parts serum and 1 per cent virus filtrate P, incubated 2 hours at 37°C

of the three normal controls exhibited no capacity to fix complement and were devoid of ability to neutralize the virus

Special attention should be called to the findings with the sera of D. R. 15-44 and 15-55, rabbits implanted respectively with the growths of D. R. 14-22 and 14-21. In D. R. 15-44 nodules 1.0 to 2.5 cm. in diameter had appeared at all six situations by the 17th day following implantation. They measured from 1.8 to 4.0 cm. on the 29th day but during the ensuing 2 weeks all abruptly vanished except the largest which dwindled to a softish nodule 1.2 cm. across. Later on this gradually enlarged and it had become a thin walled cyst 3.5 cm. across at the time of bleeding. The serum of this rabbit had no detectable capacity to fix complement, but it possessed the power to neutralize partially a 1 per cent virus filtrate (Table III). The growths of D. R. 15-55 were indolent. Palpable nodules 0.4 and 1.2 cm. across were present in only two of the six implanted situations on the 15th day. Five nodules measuring 0.4 to 2.0 cm. had appeared by the 27th day, but these dwindled during the next 2 weeks and all had disappeared when the animal was bled on the 55th day. The animal's serum had only the slightest complement fixing capacity, though it neutralized a considerable proportion of the test virus as the table shows. The results contrast sharply with those got with the sera of rabbits in which the tumors had grown big. They conform to a general rule, namely, that rabbits in which the V2 carcinoma fails to grow and those in which it regresses before it has got large, fail as a rule to develop the antiviral antibody in quantity (3).

The telltale antibody in the blood of all of the rabbits in which the cancer grew (Table III) makes plain the fact that the virus was still associated with the V2 carcinoma despite the propagation of the tumor during a period of nearly 8 months in hosts hyperimmunized against it. The fact that the antibody appeared in as high titer as previously when the growth was returned to normal animals indicates that the tumor tissue contained the usual amount of antigenic material, namely, masked or altered virus. The conclusion would seem warranted that the latter had increased to the usual extent as the V2 carcinoma grew in the hyperimmune hosts.

#### COMMENT

It is generally recognized now that viruses are protected from the action of specific antiviral antibodies so long as they remain associated with living susceptible cells.<sup>2</sup> No exception to the rule has been discerned even the necro-

<sup>2</sup> It is of theoretical interest to speculate upon the mechanism whereby living cells protect viruses from the action of circulating antiviral antibodies. Perhaps simplest is the assumption that viruses live within cells and have no contact with antibodies, these being presumably kept away by the semipermeable protoplasm. But it is conceivable that specific antiviral antibodies might still be ineffective even if they reached the vicinity of the virus. This might be the case for example, if, in the living cell, there were a special association between the cell constituents and that part of the virus to which the antibody would become attached in the absence of such an association.

tizing viruses are protected until they kill their cell hosts and thus expose themselves to the action of the antibodies they have elicited (13) The principle finds exquisite illustration in the case of the papilloma virus, which, inducing neoplastic proliferation, continues to exert its effects and to increase in amount in association with cells that are nourished by blood which would promptly render the virus inactive in the lack of cell protection (14)

The same state of affairs exists in the V2 carcinoma, and under conditions even more extreme, for the virus continues to increase even when the growth is propagated in hosts previously immunized against it, as the foregoing experiments have shown The outcome is notably different, however, in the case of certain of the extraneous viruses that sometimes ride along as passengers in transplanted cancers For, as already mentioned, virus III and vaccine virus—the only ones tested thus far in this relation—are eliminated if the tumors they ride upon are propagated in hosts previously immunized against them (6, 7) It is conceivable that the passenger viruses disappear because not sufficiently protected, but this is not necessarily so Both of the aforementioned viruses can survive in tumors after the hosts become immune to them (16),—findings which show clearly that tumor cells are capable of protecting some passenger viruses, at least against ordinary amounts of antibody

The disabilities inherent in the characters and effects of passenger viruses will sufficiently account for their disappearance from tumors propagated in virus-immune hosts Many of them sooner or later kill the cells susceptible to them, and under ordinary circumstances they rely upon passage to new cells for survival and increase None is a neoplastic virus, going along with cells that proliferate continually as result of its action Their disappearance from tumors propagated in virus-immune hosts could be explained by supposing that they infect relatively few of the tumor cells at any one time, that they seriously interfere with cellular proliferation, and that they maintain their association with the tumors chiefly by virtue of their ability to pass from dead or dying cells to living susceptible ones, instead of going along as the cells divide For under such circumstances the neutralizing antibody already present in the new host would inactivate any virus liberated from the infected cells and preclude the infection of susceptible ones, and the uninfected cells would sooner or later outgrow those hampered by the parasite

This does not mean that all passenger viruses would necessarily be eliminated by similar means Certain extrinsic viruses can adapt themselves notably well to tumor cells, as witness the persistence of fowl pest and lymphogranuloma viruses in tumors apparently unaffected by them (17) But it is one thing to go along with a tumor and another to be its cause or to modify its neoplastic character None of the passenger viruses thus far studied has either of these effects though some induce the formation of inclusion bodies in tumor cells and many cause cellular necrosis and thus deter tumor growth (4) In sum, how-

ever, the passenger viruses are all mere riders. The papilloma virus on the other hand is not only responsible for the causation and continued proliferation of tumors, but it has proved capable of rendering malignant many benign tumors of the rabbit and of hastening the growth and modifying the character of others, both malignant and benign, when brought into contact with them experimentally (15). In previous papers facts have been presented which attest to the continued neoplastic activities of the virus in partnership with the V2 carcinoma cells (3, 15).

#### SUMMARY

The V2 carcinoma—a transplanted rabbit cancer derived originally from a virus-induced papilloma and carrying in masked or altered form the virus primarily responsible for it—was propagated in five successive groups of animals all previously hyperimmunized against the papilloma virus. The cancer grew as well in the hyperimmunized hosts as in normal animals implanted during the same months, and serological tests, made when the tumor was eventually returned to ordinary hosts, proved that the virus was still associated with the carcinoma cells. It had increased to the usual extent as the tumor grew in the hyperimmune animals.

The continued increase of the neoplastic virus during propagation of the V2 carcinoma in hyperimmunized hosts contrasts sharply with the elimination of certain extraneous passenger viruses when the tumors they ride upon are grown in hosts previously immunized against them. The facts as a whole would seem to warrant a distinction between the enduring partnership of a neoplastic virus and carcinoma cells on the one hand and the casual association of passenger viruses with tumor cells on the other.

#### BIBLIOGRAPHY

- 1 Shope, R. E., *J Exp Med*, 1933, 58, 607
2. Rous, P. and Beard, J. W. *J Exp Med*, 1935, 62, 523. Kidd, J. G., and Rous, P. *J Exp Med*, 1940, 71, 469
- 3 Kidd, J. G., and Rous, P., *J Exp Med*, 1940, 71, 813
4. Levaditi, C. and Nicolau, S., *Compt rend Soc biol*, 1922, 87, 498. Rivers, T. M., and Pearce, L. *J Exp Med*, 1925, 42, 523. Levaditi, C. and Schoen, R., *Compt rend Acad sc.*, 1936, 202, 702. Levaditi, C., and Haber, P. *Compt rend Acad sc.*, 1936, 202, 2018. Pownall, and Florey, H. W., *12th Ann Rep Brit Empire Cancer Campaign*, London 1935, 105. Findlay, G. M. and MacCallum, F. O. *Tr Roy Soc Trop Med and Hyg*, 1937, 30, 507. Schoen, R. *Compt rend Soc biol*, 1938, 128, 135, *Ann Inst Pasteur*, 1938, 60, 499
- 5 Gaylord, H. R. *J Infect Dis*, 1907, 4, 155. Woglom, W. H., and Warren, J. *J Exp Med*, 1938, 68, 513, *J Hyg Cambridge Eng*, 1939, 39, 266
- 6 Andrewes, C. H., *J Path and Bact*, 1940, 50, 227
- 7 Pearce, L., personal communication to the author



- 8 Kidd, J G , *Proc Soc Exp Biol and Med* , 1940, 43, 770    *J Exp Med* , 1941, 74, 321
- 9 Kidd, J G , *J Exp Med* , 1938, 68, 703, 725, 737    Friedewald, W F , and Kidd, J G , *J Exp Med* , 1940, 72, 531
- 10 Woglom, W H , *Cancer Rev* , 1929, 4, 129
- 11 Kidd, J G , *J Exp Med* , 1938, 67, 551
- 12 Friedewald, W F , and Kidd, J G , *J Exp Med* , 1940, 72, 531
- 13 Rous, P , McMaster, P D , and Hudack, S S , *J Exp Med* , 1935, 61, 657
- 14 Kidd, J G , Beard, J W , and Rous, P , *J Exp Med* , 1936, 64, 63, 79    Kidd, J G , *J Exp Med* , 1938, 67, 551, 1939, 70, 583
- 15 Rous, P , and Kidd, J G , *J Exp Med* , 1940, 71, 787
- 16 Rivers, T M , and Pearce, L , *J Exp Med* , 1925, 42, 523
- 17 Levaditi, C , Schoen, R., and Reimié, L , *Compt rend Soc biol* , 1937, 124, 711  
Schoen, R., *Ann Inst Pasteur* , 1938, 60, 499

# THE ANTIGENIC RELATIONSHIP OF THE VIRUSES OF MENINGO PNEUMONITIS AND LYMPHOGRANULOMA VENEREUM\*

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A previous paper from this laboratory (1) described the isolation of a virus from cases of atypical pneumonia. This agent was found to be antigenically related both to the virus of meningopneumonitis originally described by Francis and Magill (2) and to the virus of psittacosis, but in other properties significant differences from the virus of psittacosis were noted. The pneumonitis virus was similar to the virus of lymphogranuloma venereum in that it formed aggregates of elementary bodies in infected cells and produced meningitis and pneumonia in mice (3), but failed to kill by the intraperitoneal route. The related meningopneumonitis strain produced glandular enlargement and other lesions in guinea pigs not unlike those produced by the virus of lymphogranuloma venereum (4). Francis and Magill (2) have noted the similarity of meningopneumonitis virus to the virus of lymphogranuloma venereum but they were unable to demonstrate any immunologic relationship of the two viruses by intracerebral cross-infection of recovered mice.

Recent studies from this and other laboratories (5) have shown that sera from human cases of psittacosis, lymphogranuloma venereum, and some cases of pneumonitis give definite cross-reactions when tested by complement fixation with antigens from the respective causative viruses. These studies also revealed that some cases of atypical pneumonia show a slightly to moderately positive dermal reaction with Frei antigen.

On the basis of active immunity tests and complement fixation studies on experimental animals, this paper will present evidence that the virus of lymphogranuloma venereum is related to other viruses which produce meningitis and pneumonia. Although previously thought to be distinct, these viruses appear to be related and as a group may represent variants descended from the same parent strain which have become adapted to various tissues and species.

\* The studies and observations on which this paper is based were conducted with the support and under the auspices of the International Health Division of The Rockefeller Foundation and in cooperation with the California State Department of Public Health.

### *Materials and Methods*

*Strains of Virus*—The virus isolated from four cases of atypical pneumonia (1) and designated strain S-F was used in suspensions of mouse brain or lung for immunization and tests for immunity. The M.L.D. for mice intranasally was 0.05 cc. of a dilution of  $10^{-2}$  or  $10^{-3}$ , intracerebrally 0.03 cc. of a dilution of  $10^{-5}$ .

Two strains of the virus of meningopneumonitis originally isolated by Francis and Magill (2) were used in the present studies. One strain MP-F97, isolated in 1934 and recently sent us by Dr. T. Francis, Jr., was shown to be antigenically related to the strain S-F (1). The other strain, MP-Cal 10 isolated in 1936, was supplied to us through the courtesy of Dr. T. B. Turner of the Johns Hopkins School of Hygiene and Public Health (13). The strain MP-F97 was used for immunization of animals in the form of suspensions of mouse lung or mouse brain. The strain MP-Cal 10 after several ferret passages and 16 intracerebral mouse passages was found to grow readily in developing eggs by inoculation into the allantoic cavity according to the method of Nigg, Crowley, and Wilson (6), and this strain also infected chick embryos by inoculation on the chorioallantoic membrane, into the yolk sac, or into the amniotic sac (7). For most of the immunity tests with the strain MP-Cal 10, the allantoic fluid of infected chick embryos was used. The M.L.D. of this material for mice was 0.05 cc. of a dilution  $10^{-5}$  intranasally and 0.03 cc. of  $10^{-7}$  intracerebrally.

The "LC" strain of the virus of lymphogranuloma venereum (LGV-LC) was sent us by Dr. Turner (13). It was passed in mice by intracerebral and intranasal inoculation, and in developing eggs by inoculation into the yolk sac (8). Unlike the virus of meningopneumonitis, it failed to multiply in the allantoic or amniotic sacs of developing eggs, and material obtained after inoculating the chorioallantoic membrane was barely infectious for mice. Mouse brain, mouse lung, and yolk sac infected with the strain LGV-LC were used in cross-immunity tests. The M.L.D. of these materials rarely exceeded  $10^{-2}$  intranasally or intracerebrally. For comparison, a strain of the virus of lymphogranuloma venereum isolated in New Haven by Dr. Marion Howard was used for immunization of mice. This strain will be designated LGV-ST<sup>1</sup>. In its general properties it was similar to the strain LGV-LC.

A few experiments were done with two strains of psittacosis virus recently isolated from parakeets. These strains were used for immunity tests as suspensions of infected mouse liver and spleen. A strain of the virus of lymphocytic choriomeningitis isolated from monkeys (15) and strain 17D of yellow fever virus were used in certain immunity experiments.

*Methods of Immunizing Mice and Other Animals*—Animals were immunized by intracerebral, intranasal, or intraperitoneal injection of active virus in all experiments. Most of the work was done with mice of the Swiss strain bred locally. White rats, kangaroo rats (*Dipodomys deserti deserti*), and Syrian hamsters (*Cricetus auratus*) were found to be susceptible to infection with the viruses of meningopneumonitis and

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<sup>1</sup> We are indebted to Dr. Marion Howard of the Yale University School of Medicine and Dr. Geoffrey Rake of The Squibb Institute for Medical Research for sending two different lines of this strain.

lymphogranuloma venereum by intracerebral or intranasal inoculation, and these animals were also used in cross-immunity tests.

Mice, rats, and hamsters were immunized by the intracerebral and intranasal routes by giving initial doses containing approximately 1/10 to 1/100 M.L.D. This was followed 2 to 3 weeks later with a dose of 1/10 to 1 M.L.D. and usually at a similar interval by a third dose containing 1 to 10 M.L.D. In some experiments the animals received a fourth injection similar to the third. The strains S-F, LGV LC, and LGV-ST were injected intraperitoneally into mice as 10 per cent suspensions of mouse brain or lung and the strains MP F97 and MP-Cal 10 as 1 per cent suspensions of mouse tissue or 10 per cent allantoic fluid. Part of the mice receiving the strains MP-Cal 10, MP F97, or S-F intraperitoneally were reinoculated 2 weeks later by the intracerebral route with 1 M.L.D. of the same strains.

Mice and hamsters being immunized with the meningopneumonitis strains were kept in a room apart from animals receiving the virus of lymphogranuloma venereum. Animals inoculated with psittacosis virus and the pneumonitis virus strain S-F were kept in strict isolation in a laboratory unit separate from that in which work was being done with the other strains.

*Controls*.—Normal mice of the same age as those being immunized were kept in boxes with wire mesh tops in the rooms with animals receiving the viruses of meningopneumonitis and lymphogranuloma venereum. In no case were these control mice found to be immune.

*Tests for Homologous and Heterologous Immunity*.—Tests for immunity were done by injection of approximately 10 M.L.D. of virus of known titer diluted from a suspension which had been previously tested and stored at  $-70^{\circ}\text{C}$ . in a solid  $\text{CO}_2$  ice box. The route of injection was the same as that of the last immunizing inoculation unless otherwise noted.

In accordance with previous observations the production of solid immunity even against the homologous strain of virus in animals inoculated by the intranasal or intracerebral routes was found to be rather uncertain (1). For this reason homologous immunity was demonstrated in each lot of animals by inoculating some of them with a lethal dose of the homologous strain either before or concurrently with the tests for heterologous immunity.

*Complement Fixation*.—Antigens for complement fixation were prepared from the allantoic fluid of 10 day chick embryos inoculated with the strain MP Cal 10 into the allantoic sac, and incubated another 5 days. In general, these antigens were found to be superior to the mouse lung antigens used in earlier work.

Antigen from the lymphogranuloma venereum virus was prepared according to the method of Rake, McKee, and Shaffer (8) by growing the virus in the yolk sac. Antigens were used at dilutions of 1/4 to 1/8 of allantoic fluid or 1/40 to 1/80 of yolk sac. Normal control antigens were similarly prepared from the allantoic fluid and yolk sacs of uninoculated embryos. For the production of experimental immune sera, guinea pigs, rabbits, and mice were immunized by intraperitoneal or intranasal inoculation with active virus of the strains MP F97, MP Cal 10, and S-F. Mice and white rats were similarly immunized with the virus of lymphogranuloma venereum. To avoid the possibility of producing heterophile antibodies, all animals with the exception of the rabbit were immunized with infected tissues from the corresponding

### Materials and Methods

*Strains of Virus*—The virus isolated from four cases and designated strain S-F was used in suspensions for immunization and tests for immunity. The M.L.D. for a dilution of  $10^{-2}$  or  $10^{-3}$ , intracerebrally 0.03 cc. of

Two strains of the virus of meningopneumonitis or Magill (2) were used in the present studies. One strain recently sent us by Dr. T. Francis, Jr., was shown strain S-F (1). The other strain, MP-Cal 10 iso<sup>1</sup> through the courtesy of Dr. T. B. Turner of the U. S. Bureau of Public Health (13). The strain MP-F97 was in the form of suspensions of mouse lung or material after several ferret passages and 16 intracerebral passages readily in developing eggs by inoculation into the method of Nigg, Crowley, and Wilson (6), and chick embryos by inoculation on the chorioallantoic membrane of the amniotic sac (7). For most of the immunization the allantoic fluid of infected chick embryos for mice was 0.05 cc. of a dilution  $10^{-5}$  intracerebrally.

The "LC" strain of the virus of lymphogranuloma was used by Dr. Turner (13). It was passed in developing eggs by inoculation, and in developing eggs by inoculation of meningopneumonitis, it failed to multiply in developing eggs, and material obtained as such was barely infectious for mice. Mouse strain LGV-LC were used in cross experiments, rarely exceeded  $10^{-2}$  intranasally or in ferrets. The virus of lymphogranuloma venereum was used for immunization of mice. In its general properties it was similar to the virus of lymphogranuloma.

A few experiments were done with ferrets from parakeets. These strains were used in infected mouse liver and spleen. A strain was isolated from monkeys (15) and strain used in immunity experiments.

*Methods of Immunizing Mice*—The virus was injected intracerebral, intranasal, or intraperitoneal. Most of the work was done with kangaroo rats (*Dipodomys deserti*). These were found to be susceptible to infection.

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<sup>1</sup> We are indebted to Dr. Mario and Dr. Geoffrey Rake of The Squibb Company for the different lines of this strain.

virus (MP-Cal 10) and survived without paralysis. About 70 to 85 per cent of mice immunized by intracerebral injection of psittacosis virus or the strains S-F, LGV-LC, or LGV ST survived inoculation with the meningopneumonitis virus, but well over half of the survivors became paralyzed in the hind legs. Two strains of the virus of lymphogranuloma venereum propagated in mouse lungs or in yolk sac produced about an equal degree of immunity. In the group of mice immunized with strains MP Cal 10, MP F97, or S-F and tested by intracerebral inoculation with the virus of lymphogranuloma venereum, the immunity produced by the meningopneumonitis virus was almost as definite as that produced by the homologous strain. Mice immunized by intraperitoneal and intracerebral injection of psittacosis virus failed to survive intracerebral inoculation with the virus of lymphogranuloma venereum.

Mice receiving intraperitoneal inoculations of the strains MP F97 and MP Cal 10 were resistant to intracerebral inoculation with the meningopneumonitis virus but did not show definite immunity to the virus of lymphogranuloma venereum injected intracerebrally. Mice receiving the latter virus intraperitoneally possessed no demonstrable immunity to intracerebral infection with either the homologous or heterologous viruses.

As shown in the last line of Table I, all of the control mice inoculated with the strain MP Cal 10 died and all but 5 of the controls receiving LGV LC died. The results of 2 experiments with this virus, in which less than 80 per cent of the control mice died, have been omitted from the summary given in Table I.

Mice immune to intracerebral inoculation with the viruses of lymphogranuloma venereum and meningopneumonitis were not resistant to infection by the same route with the virus of yellow fever or lymphocytic choriomeningitis and mice immunized with the latter agent were not immune to the lymphogranuloma virus. Two groups of mice inoculated with normal mouse brain and sterile broth had no immunity to intracerebral infection with MP-Cal 10 and mice of a third group similarly inoculated with a chick embryo tissue culture of the virus of influenza B were not resistant to LGV LC.

*Intranasal Tests*—Mice were immunized by multiple intranasal inoculations with increasing amounts of virus of the strains MP Cal 10, MP F97, LGV LC, and LGV-ST. Tests for active immunity were done 2 to 3 weeks after the last immunizing inoculation.

From the results presented in Table II it is apparent that the strain MP Cal 10 produces in the respiratory tract of mice much better immunity to itself than it does to the virus of lymphogranuloma venereum. By intranasal inoculation, the strains LGV LC and LGV ST produced a more solid immunity to the homologous virus than to the strain MP Cal 10. The results suggest a partial cross-immunity in mice immunized and tested by the intranasal route since about half the test animals survived while nearly all of the controls died. However, this cross-immunity was not as definite as that observed in the m

tracerebral tests Mice immunized by intraperitoneal and intranasal inoculation with the viruses of influenza A or B did not survive intranasal inoculation with the virus of lymphogranuloma venereum or the virus of meningopneumonitis

*Intraperitoneal Tests*—Mice receiving a single intraperitoneal inoculation of the strain LGV-LC were not resistant to intraperitoneal inoculation of a 10 per cent mouse lung suspension of the strain MP-F97 One other similar experiment in which 3 immunizing injections of the strain LGV-LC were given was inconclusive because only 1 of the controls died

In 2 experiments 14 out of 17 mice immunized by 3 intraperitoneal injections with the virus of lymphogranuloma venereum survived infection with a dose of psittacosis virus which killed all but one of 7 controls In a third experiment a larger test dose of psittacosis virus (approximately 1,000 M L D ) was used and all

TABLE II  
*Results of Intranasal Tests for Active Immunity in Mice*

Immunized with	Intranasal tests with strain			
	MP Cal 10		LGV LC	
	Deaths	Lesions in survivors	Deaths	Lesions in survivors
MP-Cal 10	1/20	*	8/18	7/10
MP-F97	—	—	4/18	8/14
LGV-LC	3/7	2/4	5/19	*
LGV-ST	8/12	4/4	0/7	0/7
Nil (controls)	26/27	1/1	27/27	—

\* Surviving mice were not autopsied because they were used in other tests

but 1 of 22 mice immunized with the strain LGV-LC died while mice immunized with the strain MP-Cal 10 survived A fourth experiment was inconclusive because less than half of the controls died As previously reported (1) the strains S-F and MP-F97 after intraperitoneal inoculation produced sufficient immunity to protect most mice against death from 1,000 M L D of psittacosis virus

### *Immunity Tests in Other Animals*

The strain MP-Cal 10 when inoculated intracerebrally or intranasally as an undiluted allantoic fluid culture regularly produced fatal infection in white rats, kangaroo rats (*Dipodomys deserti deserti*), and Syrian hamsters (*Cricetus auratus*) In hamsters and rats inoculated intracerebrally, striking neurological symptoms were seen Animals with fatal infections appeared only slightly ill 24 hours after inoculation, but later became comatose, often with marked tremors in the extremities, and died within 48 or 72 hours A sticky white discharge appeared around the eyes Animals with less severe infections

were lethargic or even comatose for a few days and later became paralyzed in the hind legs and lumbar region. In such animals extreme emaciation was the rule, but recovery occurred in about half of them after 2 to 3 weeks. Convulsive seizures were noted in some cases. The virus of lymphogranuloma venereum failed to kill hamsters regularly after intracerebral inoculation and symptoms of involvement of the central nervous system were much less pronounced than with the strain MP-Cal 10. Consequently challenge tests for immunity in rats and hamsters were done only with the strain MP-Cal 10.

TABLE III

*Intracerebral Immunity Tests with Meningopneumonitis Virus in White Rats and Hamsters*

Experiment No	Animal No	Virus	Immunization procedure			Results of intracerebral test with strain MP-Cal 10
			Material	Inoculated	Route	
1	White rat 4	LGV LC	R.L., M.B.	10 per cent 2X	I.C.	Survived, no symptoms
	White rat 1a	MP-Cal 10	A.F.	1:1 1X	I.N.	Survived, no symptoms
	White rat 2a	MP-Cal 10	A.F.	1:1 1X	I.N.	Comatose, recovered
	Hamster 11	LGV LC	H.B., M.B.	10 per cent 2X	I.C.	Partial paralysis recovered
	Hamster 12	LGV LC	H.B.	10 per cent 1X	I.C.	Partial paralysis, recovered
	White rat 5	nll	(Control)			Died 2 days, brain congested
	White rat 6	nll	(Control)			Died 3 days, brain congested
	Hamster 13	nll	(Control)			Died 4 days brain congested
2	Hamster 11a	MP Cal 10	A.F.	1:1 1X	I.C.	Paralysis recovered
	Hamster 12a	MP-Cal 10	A.F.	1:1 1X	I.C.	Paralysis recovered
	Hamster 14	LGV LC	H.B. M.L.	10 per cent 3X	I.C.	Severe paralysis, died 8 days
	Hamster 15	LGV LC	H.B., M.L.	10 per cent 3X	I.C.	Severe paralysis, died 7 days
	Hamster 16	LGV LC	H.B., M.L.	10 per cent 3X	I.C.	Severe paralysis, died 10 days
	Hamster 17	LGV LC	H.B., M.L.	10 per cent 3X	I.C.	Paralysis, recovered
	Hamster 18	nll	(Control)			Died 2 days
	Hamster 19	nll	(Control)			Died 2 days

Explanation of symbols: R.L., rat lung; M.B., mouse brain; H.B., hamster brain; A.F., allantoic fluid; I.N., intranasal. Others as in Table I.

One, two, or three successive inoculations at intervals of 2 to 4 weeks indicated by 1X, 2X, or 3X in 4th column.

*Experiment 1*—White rat 4 and 2 hamsters, Nos. 11 and 12 were immunized by intracerebral injection of 10 per cent brain suspensions containing the strain LGV LC and tested for immunity by intracerebral inoculation of 0.10 to 0.15 cc. of undiluted allantoic fluid culture of the strain MP-Cal 10. Hamsters 1a and 2a which had received both LGV LC and MP-Cal 10 by the intranasal route (see Experiment 4) were also tested by intracerebral inoculation. The results are presented in Table III.

*Experiment 2*—Hamsters were inoculated intracerebrally with the fourth hamster brain passage of the strain LGV LC followed 2 weeks later by the same strain in a 10 per cent mouse lung suspension which killed 2 normal hamsters. After 2 weeks another injection of the mouse lung preparation was given. Four immune hamsters Nos. 14, 15, 16 and 17 were tested after an interval of 3 weeks by intracerebral injection of undiluted allantoic fluid containing the meningo-pneumonitis virus strain Cal 10. Hamsters 11a and 12a, which had been immunized with LGV LC and tested



intracerebrally with MP-Cal 10, were retested at the same time by intracerebral inoculation. The results are presented in Table III.

*Experiment 3*—In a third intracerebral experiment, not shown in Table III, a smaller test dose was used and consequently all the controls did not die. Six hamsters immunized by 2 or 3 intracerebral injections of the strain LGV-LC and 6 hamsters similarly immunized with the strain MP-Cal 10 were tested for immunity by intracerebral inoculation of 3 per cent allantoic fluid from chick embryos infected with the strain MP-Cal 10. One of the hamsters immunized with LGV-LC died in 2 days, 2

TABLE IV

*Intranasal Immunity Test with Meningopneumonitis Virus in Animals Immunized with the Virus of Lymphogranuloma Venereum*

Experiment No	Animal No	Immunization procedure			Result of intranasal test with strain MP Cal 10
		Material	Inoculated	Route	
4	White rat 1	M.L.	10 per cent 3X	I.N.	Survived, no symptoms
	White rat 2	R.L.	10 per cent 1X	I.N.	Survived, no symptoms
	Kangaroo rat 1	M.L.	10 per cent 3X	I.N.	Survived, no symptoms
	Hamster 1	M.L.	10 per cent 3X	I.N.	Survived, no symptoms
	White rat 3	Nil	(Control)		Died 3 days lungs +++++
	Kangaroo rat 2	Nil	(Control)		Died 3 days lungs +++++
	Hamster 2	Nil	(Control)		Died 3 days lungs ++++
5	Hamster 3	H.L., M.L.	10 per cent 3X	I.N.	Died 3 days lungs +++++
	Hamster 4	H.L., M.L.	10 per cent 3X	I.N.	Died 4 days lungs +++++
	Hamster 5	H.L., M.L.	10 per cent 3X	I.N.	Died 7 days lungs +++++
	Hamster 6	H.L., M.L.	10 per cent 3X	I.N.	Died 8 days lungs +++++
	Hamster 7	Nil	(Control)		Died 3 days lungs +++++
	Hamster 8	Nil	(Control)		Died 3 days lungs +++++
	Hamster 9	Nil	(Control)		Died 3 days lungs +++++
	Hamster 10	Nil	(Control)		Died 39 days lungs +++++*

Explanation of symbols M.L., mouse lung, H.L., hamster lung, R.L., rat lung

\* Died, possibly with secondary infection or relapse.

others died in 9 and 12 days with paralysis, and 3 recovered after having been comatose and paralyzed for about 1 week. Three hamsters immunized with the homologous strain MP-Cal 10 developed severe paralysis and died, and 3 survived without symptoms. Three control hamsters died in 5, 9, and 12 days respectively and 1 survived.

*Summary of Intracerebral Tests (Experiments 1, 2, and 3)*—Of 13 animals immunized with the virus of lymphogranuloma venereum and tested with meningopneumonitis virus, 1 survived without symptoms, 6 developed paralysis of varying degree but recovered, 5 died later than 1 week after inoculation with severe paralysis and inanition, and 1 died in less than 1 week. Of 10 animals immunized with the homologous meningopneumonitis strain, 4 survived with-

out paralysis, 3 developed paralysis but recovered, 2 became paralyzed and died more than a week after inoculation, and 1 died in less than a week. Of 9 controls 1 survived, 2 died in more than a week, and 6 died in less than a week. The results indicate that hamsters and rats inoculated intracerebrally with the virus of lymphogranuloma are partially immune to the virus of meningopneumonitis given by the same route

*Experiment 4*—White rat 1, kangaroo rat 1 and hamster 1 were immunized by 3 intranasal inoculations with mouse lung preparations of increasing titer of the strain LGV LC. White rat 2 received a single intranasal inoculation with a 10 per cent suspension of lung from the first white rat passage of the above strain. The animals were tested approximately 2 weeks after the last immunizing dose by intranasal inoculation of 0.2 cc. of undiluted allantoic fluid from chick embryos infected with meningopneumonitis virus. The results are presented in Table IV

*Experiment 5*—Hamsters 3, 4, 5 and 6 were inoculated intranasally with 10 per cent hamster lung suspension of strain LGV LC. Subsequently at intervals of 2 weeks these animals received 2 intranasal inoculations of mouse lung material containing the same strain. Eighteen days after the last inoculation the animals were tested by intranasal inoculation of 0.2 cc. of undiluted allantoic fluid containing the strain MP-Cal 10. In this experiment the immunized animals survived only slightly longer than the controls (Table IV)

*Summary of Intranasal Tests (Experiments 3 and 4)*—Of 8 animals immunized intranasally with the virus of lymphogranuloma venereum and tested with meningopneumonitis, 4 survived without symptoms, 2 survived over twice as long as the controls but eventually died, and 2 died in the same length of time as the controls. Six control animals died in 3 days and 1 survived for 39 days. The results of these experiments are inconclusive, but suggest an increased resistance to the strain MP-Cal 10 in animals inoculated intranasally with the strain LGV LC

#### *Complement Fixation Tests with Immune Animal Sera*

Table V presents the results of complement fixation tests with sera from animals immunized with the pneumonitis virus strain S-F, meningopneumonitis virus, and the lymphogranuloma venereum virus. The sera of mice and guinea pigs immunized with the strains S-F, MP F97, and Cal 10 gave strong complement fixation with the MP-Cal 10 antigen, but relatively weak, or negative, reactions with the LGV-LC antigen. An exception to this was rabbit 33, immunized with the strain S-F in mouse lung, which developed complement fixing antibodies to both viruses in about equal titer. This serum gave slight reactions with antigen prepared from normal yolk sac and allantoic fluid. One serum (mouse 99) was slightly anticomplementary.

Mice and rats immunized with the virus of lymphogranuloma venereum developed complement fixing antibodies of a similar titer to the homologous

and heterologous viruses The apparently lower titer with the LGV antigen of some sera from animals immune to this virus was probably due to the fact that in this series of tests this antigen was somewhat less sensitive than the MP-Cal 10 antigen

TABLE V

*Results of Complement Fixation Tests with Sera of Animals Immunized with the Viruses of Lymphogranuloma Venereum and Meningopneumonitis*

Serum No	Immune to	Antigen	Serum dilution				Normal tissue Control 1 4	Serum control 1 4
			1 4	1 8	1 16	1 32		
G P 81	S-F	MP-Cal 10	+++	+++	+	0	0	0
G P 81	S-F	LGV-LC	0	0	0	0	0	0
G P 87	MP-F97	MP-Cal 10	++++	++++	++++	++	0	0
G P 87	MP-F97	LGV-LC	0	0	0	0	0	0
G.P 88	MP-F97	MP-Cal 10	++++	+++	++	0	0	0
G P 88	MP-F97	LGV-LC	0	0	0	0	0	0
Rabbit 33	S-F	MP-Cal 10	++++	++++	++++	+++	±	0
Rabbit 33	S-F	LGV-LC	++++	++++	++++	+++	++	++
Mouse 99	S-F	MP-Cal 10	++++	++++	++++	++++	++	++
Mouse 99	S-F	LGV-LC	+++	+	0	0	++	++
Mouse 115	MP-F97, Cal 10	MP-Cal 10	++++	++++	++++	++++	0	0
Mouse 115	MP-F97, Cal 10	LGV-LC	+++	+	0	0	0	0
Mouse 102	MP-F97, S-F	MP-Cal 10	++++	++++	++++	++++	0	0
Mouse 102	MP-F97, Cal 10	LGV-LC	++	0	0	0	0	0
Mouse 116	LGV-LC	MP-Cal 10	++++	++++	++++	++++	0	0
Mouse 116	LGV-LC	LGV-LC	++++	++++	+++	++	0	0
Mouse 117	LGV-LC	MP-Cal 10	++++	++++	+++	++	0	0
Mouse 117	LGV-LC	LGV-LC	++++	+++	++	0	0	0
Rat 12	LGV-LC	MP-Cal 10	++++	++++	++++	++++	0	0
Rat 12	LGV-LC	LGV-LC	++++	++++	++++	++++	0	0
Rat 16	LGV-LC	MP-Cal 10	+++	++	±	0	0	0
Rat 16	LGV-LC	LGV-LC	+	0	0	0	0	0

Various degrees of complement fixation indicated by plus signs 0, no fixation

Sera from normal guinea pigs, rabbits, rats, and mice, and sera from mice immunized with mouse lung suspensions of the virus of influenza A gave no reaction with the LGV-LC and MP-Cal 10 antigens The sera of guinea pigs immune to the strains S-F and MP-F97 contained no complement-fixing or neutralizing antibodies for the virus of influenza A or B

The antigens used in these tests gave complement fixation with the sera from cases of pneumonitis proved to be caused by the strain S-F by isolation of the virus (1) and with sera from known cases of lymphogranuloma venereum These results have been reported elsewhere (5) The antigens gave no significant fixation with normal human sera or with sera from cases of influenza or other acute upper respiratory disease

## DISCUSSION

The apparent antigenic relationship noted between the virus of meningo-pneumonitis and the virus of lymphogranuloma venereum was probably not due to accidental contamination of the strains of virus used because cross-immunity was obtained with 3 strains of meningopneumonitis virus from 2 sources and with 2 strains of the virus of lymphogranuloma venereum from different sources. In the present work factors such as chance cross-infection of animals, diet, and age which might produce increased resistance have been controlled.

Francis and Magill (2) did not describe in detail their negative experiments in mice on cross-immunity between these viruses. We are unable to account for the difference in our results unless the mice used by the above authors received smaller immunizing doses or fewer injections. It must be remembered, in this connection, that with the viruses under investigation a single sublethal dose often failed to produce demonstrable immunity even to the homologous strain.

The possibility that the cross-immunity observed in recovered animals was due to a non-specific local resistance or to the so called "interference phenomenon" should be considered. Armstrong (10) has reported that mice receiving intranasal inoculations with saprophytic bacteria possess a slight and transient resistance to intranasal infection with the viruses of St. Louis encephalitis and influenza. This was attributed to local accumulation of leucocytes. In our experiments injection of broth, normal mouse tissue, or tissue suspensions infected with viruses unrelated to the strains under investigation presumably would produce a similar accumulation of leucocytes, but no increased resistance was observed. Other authors have reported increased resistance to experimental poliomyelitis in monkeys inoculated with lymphocytic choriomeningitis (11) and to Rift Valley fever in mice inoculated with yellow fever virus (12). In all of these experiments the immunity produced was less striking and more transient than that observed in the present work. Also, in the present studies it appears that the cross-relationship was confined to a group of viruses in which other similarities were demonstrable and was not elicited by the unrelated agents of influenza, yellow fever, or lymphocytic choriomeningitis.

The experiments on active immunity in mice indicate quantitative antigenic differences between the strains studied. Thus the strain S-F from human cases of pneumonitis was apparently somewhat different from the strains LGV LC, MP Cal 10, and MP F97 because only partial cross-protection was observed. A difference apparently similar in degree was found between the virus of lymphogranuloma venereum and the strain MP Cal 10 (Tables I and II). The cross-immunity tests with the viruses of psittacosis and lymphogranuloma venereum were inconclusive, but an indirect antigenic relationship between

these two agents is indicated by the fact that meningopneumonitis virus immunized mice against both of them. Extensive studies on the relationship of psittacosis to other viruses were not attempted because similar investigations are being conducted in other laboratories.

Since the immune sera used in the complement fixation tests were produced by immunizing animals with infected tissues of the corresponding species, heterophile antibodies of normal tissues could not be concerned in the observed cross-reactions. The group specific complement-fixing antibodies in the sera of animals immunized with the virus of lymphogranuloma venereum probably resulted from an immune response either to an antigenic constituent of the virus particle or to an antigenic product of the interaction of virus and infected tissue. The corresponding group specific factor of the meningopneumonitis strains MP-Cal 10, MP-F97, and S-F apparently stimulated less antibody response because sera of mice and guinea pigs immunized with these strains, although showing a high titer with the meningopneumonitis virus, gave slight or no fixation with the virus of lymphogranuloma venereum (Table V). On the other hand, human sera from cases of pneumonitis often gave strong fixation with both antigens from lymphogranuloma venereum and meningopneumonitis (5). These differences in species response cannot be adequately explained on the basis of present observations.

Much additional work on differences in pathogenicity will be necessary before a definite classification of these viruses is possible, but a few basic criteria may be noted. Only one member of the group under consideration, psittacosis virus, is highly virulent for mice by the intraperitoneal route. The virus of meningopneumonitis kills mice only after intraperitoneal injection of massive doses. Strains of the agent of lymphogranuloma venereum were much less virulent by any route for mice than the other viruses. Differences in virulence for guinea pigs, hamsters, birds, and chick embryos have also been noted. Pinkerton (14) has observed that meningopneumonitis virus produces a fatal infection in pigeons after intracerebral inoculation while one strain of psittacosis virus does not. All of the strains studied except LGV-LC and LGV-ST produced paralysis of the hind legs of mice after an incubation period of 5 to 6 days following intracerebral injection and some caused paralysis irregularly after intraperitoneal inoculation.

The observations recorded in this paper suggest that the viruses causing certain forms of atypical pneumonia and lymphogranuloma venereum in human beings, psittacosis in birds, and other viruses which may have come from mice or ferrets should be classified together as representatives of a group of agents which in various modified forms are distributed widely in nature and cause infections of diverse character. The members of this group of viruses are characterized by the formation of elementary bodies which stain with basic aniline dyes, by the possession of antigenic components common to each, and by the

production of meningitis, pneumonia, and granulomatous infiltrations of the skin in experimental animals. Analogous groups of similar size are the *Rickettsiae*, and the pleuropneumonia like organisms. It is also apparent that criteria previously used for classification of these agents, particularly with regard to the psittacosis group, have not been adequate.

#### SUMMARY

Animals recovered from infection with the viruses of lymphogranuloma venereum, meningopneumonitis, and psittacosis, were reinoculated in cross-immunity tests with these viruses.

In mice immunized by intracerebral or intranasal inoculation a reciprocal partial cross-immunity between the viruses of lymphogranuloma venereum and meningopneumonitis was demonstrated. In preliminary experiments, similar cross-immunity between the agents of lymphogranuloma venereum and psittacosis was not definitely demonstrated.

Hamsters, white rats, and kangaroo rats recovered from intracerebral or intranasal infection with the virus of lymphogranuloma venereum were more resistant than normal controls to inoculation with the virus of meningopneumonitis.

Sera of animals immunized with the viruses of lymphogranuloma venereum and meningopneumonitis showed cross-reactions by complement fixation with antigens of these viruses.

The results indicate an antigenic relationship between the viruses of lymphogranuloma venereum and meningopneumonitis.

#### BIBLIOGRAPHY

1. Eaton, M. D., Beck, M. D., and Pearson, H. E. *J. Exp. Med.*, 1941, 73, 641.
2. Francis, T. Jr., and Magill, T. P., *J. Exp. Med.* 1938, 68, 147.
3. Shaffer, M. F., Rake, G., and McKee, C. M. *Proc. Soc. Exp. Biol. and Med.*, 1940, 44, 408.
4. Grace, A. W. and Suskind, F. H. *Am. J. Path.* 1940, 16, 169.
5. Rake, G., Eaton, M. D. and Shaffer, M. F., in press.
6. Nigg, C., Crowley, J. H. and Wilson, D. E., *Science* 1940, 91, 603.
7. Burnett, F. M. *Brit. J. Exp. Path.* 1940, 21, 147.
8. Rake, G., McKee, C. M., and Shaffer, M. F. *Proc. Soc. Exp. Biol. and Med.*, 1940, 43, 332.
9. Eaton, M. D., and Rickard, E. R., *Am. J. Hyg.*, 1941, 33, 23.
10. Armstrong, C., *Pub. Health Rep., U. S. P. H. S.* 1938, 53, 2004.
11. Dalldorf, G., and Douglass, M. *Proc. Soc. Exp. Biol. and Med.* 1938, 39, 294.
12. Findlay, G. M. and MacCallum, F. O. *J. Path. and Bact.*, 1937, 44, 405.
13. Turner, T. B., and Fleming, W. L., *J. Exp. Med.*, 1939, 70, 629.
14. Pinkerton, H., personal communication.
15. Coggeshall, L. T., *Science*, 1939, 89, 515.



# A FURTHER STUDY OF THE CROSS REACTION BETWEEN THE SPECIFIC POLYSACCHARIDES OF TYPES III AND VIII PNEUMOCOCCI IN HORSE ANTISERA\*

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A constantly increasing number of immunological cross reactions are being studied with the aid of the quantitative precipitin and quantitative agglutinin techniques, and knowledge of this phase of immunological specificity is consequently taking on a more precise character. The present contribution to this subject continues earlier work (1) on the pneumococcus Type III Type VIII cross reaction.

It was shown in the earlier studies that the reaction between the specific polysaccharide of Type VIII pneumococcus (S VIII) and an antipneumococcus (anti Pn) Type VIII horse serum, in the antibody excess region and through the equivalence zone, could be represented by the equation

$$\text{mg. antibody N precipitated} = 2RS - \frac{R^2 S^2}{A},$$

in which S = S VIII precipitated, A = antibody nitrogen precipitated at a reference point in the equivalence zone, and R = ratio of A to S at the reference point (*cf* 1, 2), an equation which may be derived from the law of mass action and which has been shown to be applicable in many immune systems (3). However, the cross reaction between the specific polysaccharide of Type III pneumococcus (S III) and Type VIII antiserum was of a distinctly different character. When S III was plotted against antibody N the resulting curve was not characteristic of the above equation but was composed of a steep initial portion, followed by a less steep, linear section. Since cross reactions are not always similar in the reciprocal sense it was thought of interest to make a quantitative study of the S VIII-anti-S III reaction, and data on this are included in the present report. An attempt was also made to isolate the antibody reactive in linear fashion in the cross reactions, as it was thought that this might show a simpler behavior toward polysaccharide than the antibody as a whole. Finally, experiments were run at 37°C. as well as at 0° in order to test the effect of temperature on the cross reaction.

\* The work reported in this communication was carried out under the Harkness Research Fund of the Presbyterian Hospital.



## EXPERIMENTAL

*Materials and Methods*—Type III and Type VIII antipneumococcus horse sera<sup>1</sup> were used after absorption with crude Type I pneumococcus "C" substance. The Type III and Type VIII pneumococcus polysaccharides (designated S III and S VIII) were prepared according to references 1 and 4.

TABLE I  
*Antibody N Precipitated from Type III Antiserum H 792 by Varying Amounts of S III and S VIII*

Amount of S used	Antibody N precipitated by S III from 1.0 ml serum	Ratio anti body N to S III in precipitate	Tests on supernatants	Antibody N precipitated by S VIII from 5.0 ml serum	Ratio anti body N to S VIII in precipitate	Tests on supernatants	Antibody N precipitated by S III from 1.5 ml serum dilution freed from cross reactive antibody	Ratio anti body N precipitated to S III in precipitate	Tests on supernatants
mg	mg			mg			mg		
0.020	0.396	19.8	Excess A*	0.250	12.5	Excess A	0.394†	19.7	Excess A
0.030	0.538	17.9	" "	0.336	11.2	" "	0.514	17.1	" "
0.050	0.664	13.3	" "	0.454	9.1	" "	0.620	12.4	" "
0.075	0.702	9.4	No A or S	0.534	7.1	" "	0.624	8.3	No A or S
0.10	0.700	7.0	" " "	0.556	5.6	" "	0.614	6.1	Trace S
0.15	0.726	4.9§	Excess S	0.690	(4.6)	" "	0.654	4.5§	Excess S
0.20	0.748	3.9§	" "	0.756	3.9§	A and S	0.658	3.7§	" "
0.25				0.764		" " "			
0.30				0.816	2.9§	" " "	0.646	3.3§	" "
0.40				0.844‡	2.5§	Excess S			
0.50				0.884	2.5§	" "			
0.75				0.952	2.7§	" "			
1.00				0.950		" "			
Equation   mg N precipitated = 23.4 S - 137 S <sup>2</sup>				Equation   mg N precipitated = 23.9 S - 143 S <sup>2</sup>					

\* A = antibody

† Single analysis only

§ Amount S in supernatant determined (6 b, c)

|| Calculated to 1.0 mg A N as follows in the experimentally determined linear equation,

$$\frac{A}{S} \text{ in precipitate} = 2R - \frac{R^2}{A} \quad S, A \text{ is put} = 1.0, \text{ changing only the slope of the line}$$

The precipitin determinations were carried out in the usual way (5, 6) by addition of increasing amounts of polysaccharide to accurately measured volumes of serum. After 2 days at 0°C the specific precipitates were centrifuged, washed twice in the cold, and analyzed for nitrogen by the micro-Kjeldahl method. All analyses were run in duplicate.

*Experiment 1 Homologous and Cross Reactions of Type III Antiserum H 792 (Bleeding 2/3/37)*—Data are given in Table I and Fig. 1 on the addition of increasing

<sup>1</sup> These sera were obtained through the kindness of Dr. Ralph S. Muckenfuss and the late Dr. William H. Park of the New York City Department of Health Research Laboratories.

amounts of S III and S VIII to the antiserum. The equations, calculated to the same antibody content, are seen to be identical before and after heterologous absorption, as in a similar experiment with Type VIII serum (1). The cross reaction, also, was

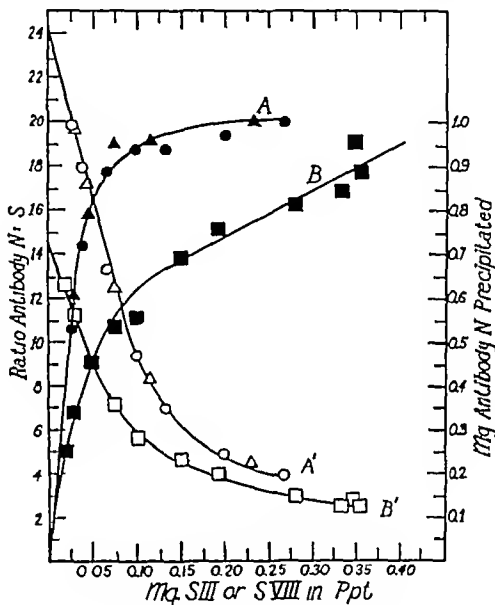


FIG. 1. Reaction of antipneumococcus Type III serum H 792 with S III and S VIII. Curves A and A' are for the homologous reaction, B and B' for the cross reaction. A' and B' are the respective A N S ratio plots. Circles give the points obtained with the original serum and triangles those after removal of antibody reactive with S VIII. Not all points in Table I are included in the plot.

similar to that for the antipneumococcus Type VIII-S III reaction (1), consisting of a steep initial segment and a less steep, nearly straight portion (slope 1.1), along which there was considerable scattering of experimental points. Upon addition of larger amounts of S, the combining ratio of antibody N to S reached a lower limit showing that the precipitate attained constant composition. The large factors by which it was necessary to multiply the analytical data for the terminal portion of the curve rendered the slope of this segment uncertain.

TABLE II

Comparison of Total Antibody (3.0 Ml Serum, 1 I) and Antibody Fractions in Cross Reaction at 0°C between S III and Anti-Pn VIII Horse Serum 644

S III added	S III in precipitate		Antibody N precipitated	Ratio anti body N to S III in precipitate based on supernatant analyzed with H 644	Supernatants		
	By H 644*	By H 792†			+ S III	+ Anti Pn III horse serum	+ H 644
mg	mg	mg	mg				
0 017 <sub>g</sub>	Total		0 344	19 5	+++		
0 031 <sub>g</sub>	"		0 500	16 0			
0 047	"		0 638	13 6	+	±	-
0 071	"		0 706	9 9	+	±	-
0 113	0 110	0 110	0 786	7 1	-		
0 188	0 176	0 174	0 940	5 3	-		
0 245	0 220	0 213	1 04	4 7			
0 261	0 229	0 223	1 10	4 8			
0 353§	0 273	0 258	1 12	4 1			
0 423§	0 273	0 273	1 13	4 1			
0 522	0 30	0 29	1 15	3 8			

Antibody N Precipitated per 6.0 Ml of H 644 A Solution by Varying Amounts of S III

0 017 <sub>g</sub>	Total	0 314	17 7	+++		-
0 037 <sub>g</sub> **	"	0 514	13 7	-		-
0 062 <sub>g</sub> ††	"	0 572	9 1	-		-
0 106§	0 100	0 600	6 0	-		+

Equation Antibody N precipitated =  $21 S - 90 S^2$ , calculated values for A at the first 3 points are 0.312, 0.521, and 0.569, respectively

Antibody N Precipitated per 6.0 Ml of H 644 B by Varying Amounts of S III

0 060 <sub>g</sub> §§	0 057		0 334	5 9		
0 113**	0 095		0 430	4 5		
0 176††	0 128		0 495	3 9		
0 282	0 156		0 516	3 3		
0 470	0 214		0 576	2 7		

\* Supernatant analyses in region of excess S III, only, carried out with anti-Pn VIII serum H 644 and quantity found deducted from amount originally taken

† Supernatant analyses in region of excess S III, only, carried out with anti Pn III serum H 792

§ 2.0 ml. of serum actually used for analyses, with corresponding amount of S III

|| Supernatants in this series were tested with H 644 A

\*\* 5.0 ml of serum actually used, with corresponding amount of S III

†† 4.0 " " " " " " " " " " " " " "

§§ 7.0 " " " " " " " " " " " " " "

||| 3.0 " " " " " " " " " " " " " "

*Experiment 2 Fractionation of Antipneumococcus Type VIII Horse Serum H 644, (1/5/37)*—The equation describing the homologous reaction of this serum was

$$\text{mg N precipitated} = 21.5 S - 108 S^2 \quad A N = 1.07 \text{ mg.},$$

practically the same as that of a bleeding from the same horse taken one year earlier

(1) The cross reaction data on this serum are given in Table II and Fig 2. In this system, as in the S VIII-anti-S III reaction, the combining ratio of antibody to polysaccharide approached a constant value. The course of the reaction curve, A, in Fig 2, was similar to that of the earlier bleeding (1). The slope of the linear portion, 2.4, was practically the same as that, 2.5 found in (1).

To 50 ml of serum H 644 a quantity of S III was added corresponding to a point at the beginning of the linear portion of the curve in order to separate, if possible, the

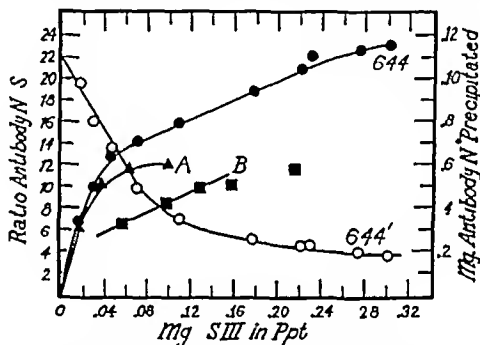


FIG 2 Reaction of antipneumococcus Type VIII serum H 644 with S III.

antibodies characteristic of the different parts of the reaction plot. The specific precipitate obtained was dissociated by Liu and Wu's modification (7) of Felton's (8) dilute alkali method, and a series of precipitin analyses was carried out with the recovered antibody solution (644 A) and S III. The curve resembled that of the first portion of the cross reaction plot. The supernatant from the original precipitation, designated 644 B, was also analyzed by the quantitative precipitin method. The slope of the 644 B line was 2.2 or almost the same as that of the original serum. The results are given in Table II and plotted in Fig. 2.

Antipneumococcus Type VIII horse sera bled from horse 909 in 1937 and in 1939 were employed for further repetitions of the cross reaction experiments. The data are omitted since they closely resembled those given in Table II and Fig 2. The slope of the linear portion of the curve for the 1937 bleeding was 2.9 and that for the 1939 bleeding was 2.8. The antibody S III ratios also approached a lower limiting value as in the case of serum 644.

*Experiment 3 Cross Precipitation at 37°C*—Data obtained at 37°C. on sera H 644

and H 909 (1939 bleeding) are given in Table III. The tubes were incubated for 0.5 hour, centrifuged at 37°C, and washed twice with saline in the cold. The supernatants were chilled and allowed to stand overnight in the ice box. Additional precipitate appeared in the supernatants which contained excess antigen. The sum of the antibody N precipitated at 37°C and that deposited after chilling did not equal the quantity precipitated in analyses run at 0°C throughout (*cf* also (6a)).

Quantitative analyses in the two cross reacting systems showed a much greater error near the antibody maximum when run at 0° than at 37°C. Even with strict temperature control successive analyses often differed by as much as 0.05 mg of N. This tendency seemed greater in certain sera than in others, and although the reason for it is not known, it recalls Goodner and Horsfall's observation (9) of coprecipitation

TABLE III

*Antibody N Precipitated at 37°C from 3.0 Ml (1 I) Type VIII Antiserum H 644 by Varying Amounts of S III*

Amount of S III added	Antibody N precipitated	Ratio antibody N to S III	Additional antibody N precipitated by subsequent chilling to 0°C	Tests on supernatants
mg	mg		mg	
0.020	0.250	12.5	0.003	Excess A
0.030	0.324	10.8	0.003	" "
0.050	0.424	8.3	0.003	" "
0.075	0.530		0.003	A and S
0.10	0.584		0.003	" " "
0.15	0.668		0.021	" " "
0.20	0.734		0.047	" " "
2.0 Ml Type VIII Antiserum 909				
0.127	0.504		0.084	Excess S
0.177*	0.528		0.070	" "

\* Three-quarters of this amount and 1.5 ml antiserum were actually used

of Types I and II antibodies from polyvalent and mixed antipneumococcus horse sera at 0° while more strictly specific precipitation occurred at 37°C

#### DISCUSSION

The quantitative theory of the precipitin reaction (2) involved the assumption that the numerous antibodies in antisera might be treated mathematically as a single substance of average reactivity, multivalent with respect to antigen, which, in turn, was multivalent with respect to antibody. In this way the aggregation and the multiple combining proportions characteristic of immune reactions such as the precipitin and agglutinin reactions could be quantitatively accounted for (3). It was, however, realized that antisera actually contain a complex mixture of antibodies differing possibly both in the number and kinds of groupings reactive with the antigen. Numerous instances were given (3) in which partial absorption of antisera with homologous antigen left behind antibodies different in reactivity from the assumed average in the original serum and characterized by a different equation

In the first paper on the Type III Type VIII cross reaction, however, it was shown that cross absorption did not result in an analogous fractionation of the antibodies with respect to their reactivity toward homologous polysaccharide (1). Although about one third of the antibodies in a Type VIII antipneumococcus horse serum could be precipitated by S III, the precipitation reaction between S VIII and the Type VIII anticarbohydrate followed exactly the same course and gave the same equation, when calculated to the same antibody content, whether carried out in whole serum or in serum deprived of the considerable proportion of antibody cross reactive with S III. This has since been confirmed in parallel studies on other Type VIII antisera. It will be noted from Table I and Fig. 1 that a similar state of affairs obtains in Type III antiserum, the homologous reaction and equation, recalculated to the same amount of antibody, remaining the same after removal of the antibodies precipitated by S VIII. This may be taken to indicate a random distribution, among the antibodies of different reactivities, of groupings or configurations capable of reacting with heterologous specific polysaccharide.

While the homologous reaction pairs, S III anti S III and S VIII-anti-S VIII yielded curves of the type previously observed in horse sera (1, 2), the heterologous pairs, S III anti S VIII (1) and S VIII-anti S III followed a different but mutually similar course. After an initial steep, curving portion in the plots (Figs. 1 and 2) resembling the homologous reactions there was a relatively sharp transition into a less steep, linear portion suggestive of the reaction plot found by Scherp for Type I meningococcus specific polysaccharide in polyvalent antimeningococcus horse sera (10), and in exaggerated measure, conforming to Goodner's presentation (11) of even homologous reaction curves as a series of small linear segments. Even along the linear portion of the cross reaction curve the composition of the specific precipitate varied, but tended to become constant at lower antibody N to S ratios as the amount of specific polysaccharide was increased. With 10 times the quantity of S giving maximum cross precipitation partial inhibition ensued in the S III-anti S VIII reaction while in the S VIII anti S III system precipitation was merely delayed, not diminished. A further 5-fold increase in S resulted in complete inhibition of precipitation in the former system and nearly complete inhibition in the latter. In both reactions, then, soluble compounds are possible with lower antibody N S ratios than the final constant ratio insoluble compound, just as in homologous precipitation reactions (*cf.* also (12)).

It was noted that removal of the cross reacting antibodies corresponding to the initial curved segment of the plot resulted in the failure of about one-half of the remaining cross reacting antibody to precipitate with S III. A similar effect has been observed in the serial precipitation of many antisera by small amounts of antigen and has been interpreted on the assumption that the non precipitable portion of antibody is univalent with respect to antigen and can take part in aggregate formation only in the presence of sufficient multivalent

antibody (3, 13) On this basis, then, the entire linear portion of the cross reaction curve would be due to the addition of univalent (and by itself non-precipitable) antibody to S III-A aggregates formed with the multivalent antibody of the initial segment of the curve In the attempted separation of the antibody into portions characteristic of the two segments it would seem that sufficient multivalent antibody remained with the linear portion, 644 B, to permit precipitation by S III of roughly one-half of the total cross reacting antibody This is borne out by the failure of the line B in Fig 2 to pass through the origin The interpretation given also accounts for the drift in composition noted in Table II

If one considers the linear segment as a separate curve, apart from the remainder of the plot, it is found that the quantity of antibody precipitated is directly proportional to the amount of S III added Since combining proportions of antigen and antibody remain constant over this range, it is possible to calculate an immunological equivalent weight for S III in the cross reaction The proportionality constant of antibody N to antigen, or the slope, equals 2.5 for serum H 644, multiplied by 6.3 this yields a protein polysaccharide weight ratio of about 16 If 1,000,000 be taken as the molecular weight of horse antibody to pneumococcus (14), and its valence with respect to S III equal to 1, as discussed above, the equivalent weight of S III is found to be 62,000, which equals about 180 glucuronoglucose units This would represent a minimum value for the molecular weight of S III A similar calculation for S VIII, based on Experiment 1, leads to the value 140,000

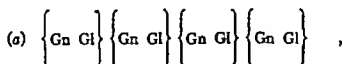
Of the numerous instances of cross reactivity studied some have been found to be reciprocal and others unilateral, but criteria are lacking by which predictions can be made as to which behavior a given cross reaction will show The specificities and cross reactivities of azoantigens containing sugars and sugar acids as determinant groups have been studied by Avery and Goebel (15) and by Goebel (16) and have been related to the chemical structure and spatial relationship of the sugar haptens employed The present study permits a correlation between the chemical constitution of two naturally occurring polysaccharides, S III and S VIII, and the quantitative behavior of the reciprocally similar cross reactions in both directions between these polysaccharides and horse antisera to Types III and VIII pneumococci

Since S III (17) and S VIII (18) contain the same aldobionic acid as a structural unit, a measure of cross reactivity is to be expected Evidence has been given, however, that the serologically reactive unit is a larger portion of the polysaccharide molecule than a single chemical structural unit (19, 1) While S III is a polymer of the aldobionic acid unit, S VIII contains, in addition, approximately two glucose molecules for every aldobionic acid residue (1, 18) Cross precipitation in either the S III-anti-S VIII system or the S VIII-anti-S III system would therefore involve only that fraction of the antibodies carrying reactive groupings of suitable configuration (*cf* also Hooker and Boyd (20))

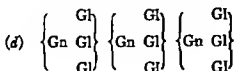
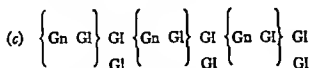
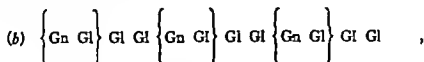
An appreciable portion of the cross reacting fraction would be expected to contain more than one reactive grouping per antibody molecule. It might also be predicted from a knowledge of the structures of S III and S VIII (as yet complete only for S III (21)), that, weight for weight, the polyaldohionic acid S III would be a more efficient cross precipitant for anti-S VIII than S VIII for anti-S III. This would follow, because in S VIII the common aldohionic acid unit, to a multiple of which the cross reactivity is ascribed, comprises only about 60 per cent of the molecule whereas S III is wholly a polyaldohionic acid. That this prediction is borne out is shown by the slopes of the linear portions of the cross reaction curves. In the S III anti-S VIII system these slopes are more than twice as great as that of the single S VIII-anti S III system studied, so that along this portion of the curve more S VIII is required to precipitate a given weight of anti S III than is necessary in the case of S III to precipitate the same weight of anti S VIII. This not only holds for the linear segments of the curves, but also for the initial steep portions, as may readily be determined either from the intercepts of the line connecting the antibody N/S ratios of the first points in the curves, or by noting on Figs. 1 and 2 the amounts of antibody N brought down in the cross reactions by 0.01, 0.02, and 0.03 mg. of S III and S VIII, respectively.

Since the cross reactivities of S III and S VIII seem reciprocally equal to the proportion of common aldohionic (cellohiuronic) acid contained in each polysaccharide, the cross reactions being of the same type, but with numerical differences of the order expected from as much of the chemical structures as is known, a further, admittedly speculative, deduction might be drawn.

If one writes the structure of S III in conformity with (21) but schematically as

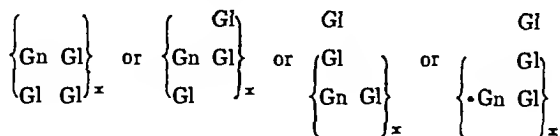


in which Gn = glucuronic acid and Gl = glucose residues, and brackets indicate cellohiuronic acid residues, a number of alternative formulas for S VIII containing the same unit suggest themselves





In (c) and (d) the side-chain glucose residues are arbitrarily placed, if they were shifted, or placed in tandem in (d) the structural type would remain much the same. The great similarity of the cross reactions would seem to require as great a similarity in the structure of the two polysaccharides as possible. (a) and (d) have the same polyaldobionic acid chain, so that (d) or one of its alternative forms,



would be a distinctly probable structure, if serological data alone are considered. But unless S III and S VIII have greatly different molecular weights this type of structure seems less probable than one of the linear forms since the viscosities of the two polysaccharides in undegraded form (4, 1) are not very different. If one compares (b) and (c) with (a) and assumes similar linkages and spatial arrangements it becomes evident that in (b) every cellobiuronic acid unit would correspond spatially with alternate cellobiuronic acid units in (a), while (c) would show a periodicity of this kind only between alternate units in (c) and every third unit in (a). Therefore, taking all available chemical, physical, and quantitative serological evidence into consideration, (b) would seem the most probable structure for S VIII although (d) and (c) cannot, of course, be excluded. A definite answer must await methylation studies such as have led to the elucidation of the structure of S III.

Another rather unexpected by-product of the quantitative study of these cross reactions emerges from a consideration of the initial steep section of the curve in the S III-anti-S VIII reaction. In the equation of the line connecting the first four antibody N/S ratio points on curve 644', Fig. 2, the slope,  $-R^2/A = 171$ , and  $2R$ , the intercept on the ordinate,  $= 22 A$ , therefore,  $= 0.7$ . Since only the slope is affected in putting  $A = 1.0$ , the equation of the curve, obtained by multiplying both sides of the linear equation by  $S$ , becomes

$$\text{mg antibody N precipitated} = 22 S - 120 S^2, \text{ at } A = 1.0$$

The equation of the homologous S VIII-anti-S VIII reaction calculated to the 1.0 mg. A level is

$$\text{mg antibody N precipitated} = 21.5 S - 116 S^2$$

or practically identical with that of the cross reaction. Unfortunately the data given in (1) cannot be used for an additional test of this relationship since only one point on this part of the curve was determined. However, the dissociated antibody (644 A) from the fractionation of serum 644 (Table II, and Fig. 2, curve A) also has the same equation,

$$\text{mg antibody N precipitated} = 21 S - 114 S^2,$$

as that of the homologous reaction when calculated to 1.0 mg. of cross reacting antibody N. The virtual identity of the equations indicates that an appreci-

able fraction of the antibody reacts in exactly the same way with S III and with S VIII. As far as can be determined by the sensitive quantitative method, this fraction of the antibody fails to distinguish between the two polysaccharides. This serves again to emphasize both the close structural relation between the two polysaccharides as well as the sharp differences in reactivity between different fractions of the antibodies elicited in an animal by immunization with a single antigen (*cf* also (3)). These results also extend an earlier observation that the antibody dissociated from a specific precipitate of S III and anti S VIII was entirely precipitable by either polysaccharide (22).

A corresponding antibody fraction with identical reactivity toward S III and S VIII was not found in the antipneumococcus Type III serum studied (Table I and Fig 1). It will be noted that the equation of the initial segment of the cross reaction curve, calculated to 1.0 mg of cross reacting antibody N in the same way as in the preceding instance,

$$\text{mg antibody N precipitated} = 14.5 S - 52.6 S^2$$

is distinctly different from that of the homologous reaction,

$$\text{mg antibody N precipitated} = 23.4 S - 137 S^2$$

at the same antibody N level. The failure of the two cross reactions to show strictly reciprocal behavior in this sense, while not predictable on the basis of available information, is at least in accord with the points stressed, since, as noted above, S VIII is only in part a polycellobiuronic acid such as S III.

Thus the S III anti S VIII and S VIII anti-S III cross reactions show, in general, a reciprocal character that might have been expected from the close structural similarity of the specific polysaccharides comprising the hapten portion of the distinctive antigens of the two pneumococcus types. Quantitative analysis of the cross reactions, has, however, brought to light distinct differences in the course of the two reactions and permitted a correlation between these differences and the known chemical structures of the two polysaccharides.

It is also evident that at least three distinct kinds of anticarbohydrate<sup>2</sup> are evoked in horses in response to the stimulus of a type specific pneumococcus antigen such as, for example, that of Type VIII. Two of these forms make up the cross reactive fraction, which usually comprises one-quarter to one third of the total. As already noted, this portion is completely precipitable by S III or by S VIII. It may be fractionated by means of the cross reacting polysaccharide, S III, into (1) a portion characterized by a sharply ascending reaction curve, and (2) a fraction showing a linear segment and ultimately constant composition of the specific precipitate. This, if it could be obtained entirely separate from the other fraction, would appear to be univalent with

<sup>2</sup> Antibodies to the somatic C-substance need not be considered here, since they were removed from all antisera in advance.

respect to S III, although not with respect to the homologous S VIII. Finally, after separation of the cross precipitable antibody from the antiserum, the principal antibody fraction (3), at least two-thirds of the total, is found to be rigidly type specific in that cross precipitation between Types III and VIII does not occur. Even this antibody is not homogenous, but is composed of fractions of varying reactivity toward the homologous polysaccharide as shown by the identity of its characteristic equation with that of the antiserum as a whole. The concept "antibody" would therefore seem to refer, not to serum globulin modified in a single manner, but to a series of modified globulins separable and identifiable as distinct fractions and limited in number mainly by the cross reactivities and quantitative criteria available for their characterization. These complexities are, however, far from hopeless, as they may be accounted for even quantitatively on the basis of varying numbers and kinds of reactive molecular groupings, for example, as in the present communication and in earlier papers from this laboratory.

#### SUMMARY

1 The cross reaction of the specific polysaccharide of Type VIII pneumococcus with Type III antipneumococcus horse serum has been studied quantitatively and found similar to the S III-anti-S VIII reaction.

2 Contrasted with the general similarity of the two-segment reaction curves were distinct qualitative and quantitative differences in the course and character of the reciprocal reactions with respect to each segment.

3 These differences could be interpreted in terms of the known chemical differences between the specific polysaccharides of the two types. A minimum molecular weight of 62,000 was calculated for S III and 140,000 for S VIII.

4 It was also found possible to fractionate the Type VIII antibody into portions characteristic of each segment of the cross reaction curve. At least three different kinds of Type III and Type VIII anticarbohydrates were identified.

#### BIBLIOGRAPHY

- 1 Heidelberger, M., Kabat, E. A., and Shrivastava, D. L., *J. Exp. Med.*, 1937, 65, 487.
- 2 Heidelberger, M., and Kendall, F. E., *J. Exp. Med.*, 1935, 61, 563.
- 3 For reviews see Heidelberger, M., *Bact. Rev.*, 1939, 3, 49, *Chem. Rev.*, 1939, 24, 323.
- 4 Heidelberger, M., Kendall, F. E., and Scherp, H. W., *J. Exp. Med.*, 1936, 64, 559.
- 5 Heidelberger, M., Kendall, F. E., and Soo Hoo, C. M., *J. Exp. Med.*, 1933, 58, 137.
- 6 (a) Heidelberger, M., and Kendall, F. E., *J. Exp. Med.*, 1935, 61, 559. (b) Heidelberger, M., and Kendall, F. E., *J. Exp. Med.*, 1935, 62, 697. (c) Heidelberger, M., and Kendall, F. E., *J. Exp. Med.*, 1932, 55, 555.
- 7 Liu, S., and Wu, H., *Chin. J. Physiol.*, 1938, 13, 449.

8. Felton, L. D , *J Immunol* , 1932, 22, 453, and earlier papers.
- 9 Goodner, K., and Horsfall, F L., Jr , *J Exp Med* , 1937, 66, 437
- 10 Scherp, H W *J Immunol* , 1939, 37, 469
- 11 Goodner, K., *Proc 3rd Internat Cong Microbiol.*, New York, 1940, 818
- 12 Heidelberg, M., and Kendall, F E , *J Exp Med* , 1929, 50, 809
- 13 Heidelberg M , and Mayer, M., *J Bact* , 1940, 39, 37 Heidelberg, M.,  
Treffers H P , and Mayer, M , *J Exp Med* , 1940, 71, 271
- 14 Kabat, E A., *J Exp Med* , 1939, 69, 103
- 15 Avery O T , and Goebel, W F , *J Exp Med* , 1929, 50, 533 Avery, O T ,  
Goebel, W F , and Babers, F H., *J Exp Med* , 1934, 60, 599, and numerous  
other papers.
- 16 Goebel, W F , *J Exp Med.*, 1940, 72, 33 Goebel, W F , and Hotchkiss, R. D.,  
*J Exp Med* , 1937, 66, 191
- 17 Heidelberg, M , and Goebel W F , *J Biol Chem* , 1926, 70, 613, 1927, 74, 613
- 18 Goebel, W F , *J Biol Chem* , 1935, 110, 391
- 19 Heidelberg, M , and Kendall, F E., *J Exp Med* , 1933, 57, 373
- 20 Hooker S B , and Boyd, W C., *Proc Soc Exp Biol and Med* , 1941 47, 187
- 21 Hotchkiss, R. D , and Goebel, W F , *J Biol Chem* , 1937 121, 195 Reeves,  
R. E and Goebel, W F *J Biol Chem* , 1941, 139, 511 Adams, M H.,  
Reeves R. E., and Goebel, W F , *J Biol Chem* 1941, 140, 653
- 22 Heidelberg, M., and Kabat, E A., *J Exp Med* , 1938 67, 181



# THE QUANTITATIVE DETERMINATION OF INFLUENZA VIRUS AND ANTIBODIES BY MEANS OF RED CELL AGGLUTINATION

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In a recent brief communication we described the agglutination of chicken red blood cells by materials containing the PR8 and Lee strains of influenza virus (1). Furthermore, it was shown that the addition of specific immune serum inhibited the agglutination in the presence of the homologous virus, but not when heterologous strains were used. This paper presents the results of further experiments related to these phenomena. The first experiments deal primarily with the correlation between the agglutinating capacity of virus suspensions and their infectivity for mice. A greater number of experiments have been directed toward correlating the agglutination inhibiting power of various sera with their virus-neutralizing capacity. Experiments primarily concerned with the mechanism of agglutination will be discussed in a later report.

## *Methods*

*Preparation of Virus Suspensions*—The allantoic fluid of infected chick embryos has been used as the principal source of virus throughout the work reported here. Eleven-day old white Leghorn embryos were used for inoculation. The shell was first sterilized with alcohol, and a small puncture was made over the air sac with a blunt dissecting needle. A second hole was made over the region where the chorioallantoic vessels were visible. The point of a 23 gauge needle was inserted into the latter hole, and 0.1 cc. of virus suspension was injected just beneath the egg shell into the allantoic sac. Usually infected allantoic fluid, diluted to  $10^{-3}$  or  $10^{-4}$  with saline, was used for the inoculum. The holes were sealed with paraffin and the eggs were incubated at 37°C.

After 48 hours the allantoic fluid was removed from the eggs with a minimum of contamination with embryonic red cells. While this was slightly difficult technically, the increased care was justified by the higher virus titer of the fluid obtained. A moderate number of red cells although quickly removed from the fluid by centrifugation, took out 50 to 90 per cent of the virus originally present. The eggs were opened by removing the shell over the air sac with forceps, and care was taken not to tear the chorioallantoic membrane. Closed, pointed forceps were used to pierce the exposed membrane near its outer margin. The forceps were then allowed to open,

and the membrane was held up like a tent. This opened the allantoic sac so that the fluid could be aspirated with a syringe and large bore needle (13 gauge) or with a rubber bulb on a capillary pipette. Care was taken not to aspirate any blood which ran down the torn membrane. An average of 4 to 5 cc. of cloudy fluid was obtained from each egg, and occasionally as much as 10 cc. could be aspirated.

The allantoic fluid from several hundred eggs was pooled and then redistributed into small lusteroid tubes. These tubes were quickly frozen and stored at  $-72^{\circ}\text{C}$  in a  $\text{CO}_2$  ice box. Under these conditions of storage both the agglutinating capacity and the virus titer as determined in mice have remained essentially unchanged for several months.

*Strains of Virus Used*—Allantoic fluid was prepared in the manner described above using four different strains of influenza virus: the mouse-adapted PR8 and the WS strains of influenza A virus, the Lee strain of influenza B virus, and swine influenza virus. All except the swine strain had had several passages in eggs prior to use. The allantoic fluid containing swine virus was prepared from eggs which had been inoculated with infected mouse lung.

*Preparation of Chicken Red Cells*—Except when otherwise noted, the cells used for all the tests have been a 2 per cent suspension of adult chicken red cells. Chickens were bled from a wing vein into a syringe containing 10 cc. of 2 per cent sodium citrate. The citrated blood was filtered through gauze to remove the small clots, and the cells were washed three times in saline. The cells were removed by low-speed centrifugation after each washing. After the third washing the packed cells plus two volumes of saline were put into 15 cc. graduated centrifuge tubes and spun at 900 R.P.M. for 8 minutes. The sedimented red cells were diluted with saline to fifty times their volume. The red cell count on such 2 per cent suspensions was 160,000 to 180,000 per c. mm. The chickens were usually bled on the first day of the week, and the red cells were washed and stored at  $4^{\circ}\text{C}$  after packing the final time. They were diluted just before use. The red cells, when stored in this way, could be preserved in a satisfactory condition for at least a week.

*Titration of the Red Cell Agglutinating Capacity of Influenza Virus Suspensions*—The test tubes used in all the *in vitro* agglutination experiments were 7 cm. long and had an internal diameter of 0.8 cm. For agglutination titrations, series of twofold dilutions of the virus suspensions were made in saline. To 1 cc. of each dilution was added 1 cc. of the 2 per cent red cell suspension. The tubes were immediately shaken until the cells were well mixed. The titrations then stood at room temperature, without being shaken or disturbed, for 1 hour before reading.

*Titration of Agglutination-Inhibiting Substances in Sera*—The sera to be tested were diluted in twofold steps in saline. To 0.5 cc. of each serum dilution was added 0.5 cc. of virus suspension, using the same concentration of virus in each tube. The virus suspension had previously been diluted to four times the desired final concentration. To the mixture of serum and virus was added 1 cc. of a 2 per cent red cell suspension, and the tubes were shaken until the cells were well dispersed. The agglutination was read at 1 hour. Throughout this paper the concentrations of serum and virus suspension are given in terms of the final concentration, after the red cells have been added. In certain inhibition experiments the dilutions of serum were made in normal horse serum or normal ferret serum instead of in saline, so that the total amount of

serum in each tube (normal plus immune) would be the same. All ferret sera were inactivated at 56°C. for 30 minutes before use. The human sera were not inactivated.

Two controls were included in each test: a positive control containing red cells, virus suspension, and the same diluent used in making the serum dilutions, and a negative control containing red cells and saline but no virus.

*Grading the Agglutination Tests*—The tests were all read at 1 hour's time and were viewed against a bright white background. For this purpose a 15 watt "daylight" fluorescent light proved to be the most useful. The racks were placed directly against the light.

The amount of red cell sedimentation, rather than visible agglutination, was taken as the index of the degree of reaction since it was easier to see. In the negative control tube the red cells slowly settled during the hour before the test was read. About 3 to 4 mm from the top of the fluid column was a sharp sedimentation boundary above which the saline was clear. The cells settling out at the bottom formed a small round, sharply outlined disk, but the density of the lower three fourths of the cell suspension remained unchanged.

In the tubes in which agglutination occurred, the masses of aggregated cells usually settled to the bottom in 1 hour. Those cells which remained in the supernatant fluid were usually finely dispersed and not granular, although occasionally clumps adhered to the sides of the tubes. In the tubes in which agglutination was most marked only a thin veil of non granular cells was left in suspension. With decreasing degrees of agglutination the density and cell concentration of the supernatant fluid approached that of the negative control tube. It was the density of the cells remaining in suspension which was used for reading the tests.

In order to make the grading of the reaction more objective the density of the cellular suspensions in the various tubes was compared with the density of standard suspensions of red cells in saline. These standard suspensions were made from the same red cell preparation used in the tests. The tube being read was placed between two tubes of the same standard red cell concentration and the density of the cells in the lower half of the tube was compared with the known dilutions. For the standard suspension, red cells were prepared in concentrations of 1.0, 0.75, 0.50, and 0.30 per cent. Tubes in which the density fell between that of the 1.0 per cent and the 0.75 per cent standard were called one plus. Those with a density between that of the 0.75 and the 0.50 per cent standards were called two plus, those between 0.50 and 0.30 per cent were graded three plus, and all tubes with a density less than that of the 0.30 per cent suspension were designated four plus.

With the increasing degrees of agglutination the size of the disk in the bottom of the tube also increased. In the negative control tube the disk in the bottom was small and sharply outlined. When agglutination occurred the margins of the bottom disk often had a characteristic irregular lacy pattern made up of clumps of cells. This was especially true with very slight degrees of agglutination. When a tube had this granular pattern on the bottom with no decrease in density of the supernatant suspension it was called plus-minus.

The end point in all agglutination titrations and serum inhibition tests has arbitrarily been taken to be the dilution where two plus agglutination occurs. If two plus agglutination does not occur in any tube, the end point is assumed to be half way



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between two serial dilutions, one showing more and the other less than two plus agglutination

*Tests in Mice*—The serum neutralization tests in mice were done in the manner described by Horsfall (2) except that twofold instead of fourfold serum dilutions were used. The virus titrations in mice were done in the usual way except that dilutions of virus were made in steps of  $10^{-0.5}$  instead of  $10^{-1}$ . The immune ferret sera used were obtained by bleeding ferrets 14 days after inoculation intranasally with living virus.

#### EXPERIMENTAL

*Correlation of Agglutination Titers and 50 Per Cent Mouse Mortality Titers of Suspensions of Influenza Virus*—In the first experiment different preparations of the same strain of influenza virus (PR8) were tested by *in vitro* agglutination and by intranasal inoculation of mice in order to compare the titer obtained.

Two preparations of infected mouse lung, one of allantoic fluid, and two of ground whole chick embryo, were used. Each suspension was centrifuged at low speed until it was clear. Some of the preparations were stored for as long as 6 weeks at  $-72^{\circ}\text{C}$ , while others were tested immediately after harvesting. *In vitro* titrations were set up as described under Methods. At the same time mouse titrations were done on these suspensions using dilutions of virus in  $10^{-0.5}$  steps.

The results, recorded in Table I, show that the mouse lethal titers and the agglutination titers of these suspensions parallel each other over a wide range of virus concentration. The figures in the last column of the table represent the concentrations of 50 per cent mouse lethal doses in the *in vitro* end point dilution (+ +) of the various virus suspensions. The relatively slight variation in these concentrations ( $10^3.5$  to  $10^3.9$ ) when virus from very different sources was tested suggests that under these conditions the *in vitro* titration may be a good index of the amount of lethal influenza virus in a suspension.

However, it must be emphasized that this correlation holds only when freshly prepared or well preserved virus suspensions are tested, that is to say when all of the virus presumably is pathogenic, for it can be demonstrated that the infectivity of the virus can be destroyed without destroying the capacity of agglutinating red blood cells. For example, when infected allantoic fluid was heated at  $56^{\circ}\text{C}$  for 15 minutes, the infectivity of the preparation was completely lost, while the *in vitro* agglutination titer remained undiminished. Likewise, when infected allantoic fluid was allowed to stand at room temperature for several days, the mouse lethal titer slowly diminished but the *in vitro* titer remained constant. Therefore, to measure the infectivity of a preparation by the *in vitro* test, the suspension must contain no great proportion of inactivated virus.

Another exception to the correlation between the two methods of titration is afforded by infected ferret lung. A suspension of ground infected ferret lung

TABLE I  
*Comparison of Agglutination and Mouse Mortality Titration on Different Preparations of PR8 Virus*

Source of virus	Dilution of virus										Saline control	In vitro titration	50 per cent mouse mortality titration	Mouse lethal titration titration
	1:5	1:10	1:20	1:40	1:80	1:160	1:320	1:640	1:1280	1:2560				
Mouse lung 335th passage	++++	++++	++++	++++	++++	++++	++++	++++	++	±	0	1,280	10 <sup>-8.7</sup>	10 <sup>3.8</sup>
Mouse lung 336th passage	++++	++++	++++	++++	++++	++++	++++	++++	±	0	0	960	10 <sup>-8.3</sup>	10 <sup>3.5</sup>
Allantoic fluid	++++	++++	++++	++++	++++	++++	++	+	0	0	0	320	10 <sup>-8.0</sup>	10 <sup>3.5</sup>
Ground whole chick	++++	++++	++	0	0	0	0	0	0	0	0	20	10 <sup>-5.2</sup>	10 <sup>2.9</sup>
Ground whole chick	++++	++++	±	0	0	0	0	0	0	0	0	15	10 <sup>-4.9</sup>	10 <sup>2.7</sup>

\* Expressed as the number of 50 per cent mouse mortality doses in 0.05 cc. of the dilution of virus suspension which caused two plus agglutination of red cells.

containing a mouse-adapted strain of PR8 virus at a high titer would not agglutinate red cells in any dilution. That this may be due to inhibitory substances in the ferret lung is shown by the fact that when ground normal ferret lung is added to infected allantoic fluid, red cell agglutination is inhibited.

While the experiment summarized in Table I shows a certain consistent relationship between mouse lethal titer and agglutination titer when different preparations of the same strain are tested, an experiment recorded in Table II shows the relationship between these two titers when different strains of influenza virus in allantoic fluid are compared. It will be seen that four different strains, some of them antigenically unrelated, showed a remarkable constancy in their *in vitro* titer, differing by not more than twofold. Simultaneous mouse titrations on the same preparations, however, demonstrated widely differing capacities to kill mice. For example, the WS strain, which in this experiment has

TABLE II

*Comparison of Agglutination and Mouse Mortality Titrations on Four Different Strains of Influenza Virus*

Virus strain	Dilution of virus						Agglutination titer	50 per cent mortality titer
	1 32	1 64	1 128	1 256	1 512	1 1024		
PR8	++++	++++	+++	++	±	0	256	10 <sup>-6.0</sup>
WS	++++	++++	++	0	0	0	128	10 <sup>-6.5</sup>
Swine	++++	++++	++	0	0	0	128	10 <sup>-4.2</sup>
Lee	++++	++++	+++	++	0	0	256	10 <sup>-4.0</sup>

the highest mortality titer in mice, gives a lower *in vitro* titer than the Lee strain, which has the lowest mortality end point in mice.

It is clear from this experiment that the agglutinating capacity of virus suspensions and their ability to cause lesions or death are independent variables when different virus strains are compared. In view of their wide variation in this latter respect, it was surprising that the allantoic fluid preparations of all the strains so far studied showed such a constant agglutination titer.

*Measurement of Agglutination-Inhibiting Substances in Serum*—In a previous paper (1) it was stated that when sera (human and ferret) which contained a high titer of influenza-neutralizing antibodies were added to virus suspensions, these virus suspensions would no longer agglutinate red cells, even though the immune serum was present in very low concentration. It was also shown that the amount of this inhibiting substance in a serum could be titrated by determining at what dilution of serum the inhibitory effect was no longer demonstrable. Before going further into the study of this phenomenon it was considered of importance to investigate the inhibitory properties of normal sera.

Serum inhibition tests were done on a number of normal ferret sera, using

both the PR8 and the Lee strain of virus. The sera were heated at 56°C for  $\frac{1}{2}$  hour, and serial twofold dilutions in saline were made. To these dilutions a constant amount of infected allantoic fluid was added, and the amount of agglutination was read 1 hour after adding red cells. The results with three such sera, shown in Table III, demonstrate that there was an inhibitory substance present in normal ferret serum, and that with low dilutions of serum the inhibition was active against both viruses tested. Similar inhibition was demonstrated with mouse, rabbit, and guinea pig sera, but practically no inhibitory effect was demonstrable with horse serum. This inhibitory factor was partly destroyed by heating the serum to 56°C for  $\frac{1}{2}$  hour. The possible presence of a normal inhibitory substance in human serum will be discussed later.

Although the presence of an agglutination inhibiting substance in normal serum complicated the titration of inhibition due to influenza virus antibodies, it was relatively easy to obviate this difficulty. When a difference in inhibition titer between two sera from the same individual or from the same animal was measured, the change in titer was assumed to be due to antibodies, since the amount of normal inhibitory substance was probably the same in both sera. Also the inhibition titer of most immune ferret sera was very high, considerably beyond the range where the normal inhibition was active. When titers from different animals of the same species were compared, the immune serum dilutions were made in normal serum from the same species so that the total amount of serum in each tube (normal plus immune) was the same. This made it possible to dilute out the inhibitory effect due to antibodies while the normal inhibitory effect was kept constant.

*The Serological Specificity of the Serum Inhibition Test Using Immune Ferret Sera*—The antigenic relationships of various strains of influenza virus have been extensively studied by several authors. These studies have shown that influenza A virus strains are antigenically distinct from the Lee and T.M. strains of influenza B virus (3, 4). Also differences have been demonstrated between various strains of influenza A virus (5-7), and swine influenza virus has been shown to be distantly related to influenza A strains (8, 9). The following experiment was performed to see whether or not the inhibition test is sufficiently sensitive to detect the antigenic differences and similarities demonstrable by other methods.

The PR8 and W.S. strains of influenza A virus, the Lee strain of influenza B virus and swine influenza virus were used. Allantoic fluid preparations of the virus strains and ferret antisera were prepared as described under Methods. Since high concentrations of normal ferret serum inhibit agglutination of the red cells, all immune serum dilutions were started at 1:32. All dilutions of the immune sera were made in normal ferret serum so that the final concentration of serum in each tube (normal plus immune) was 1:32. Agglutination titrations of the four virus preparations were also



made in 1/32 normal ferret serum. The dilution of allantoic fluid used in the inhibition tests was twice the concentration which caused a two plus reaction in the agglutination titrations. With the PR8 Lee, and swine strains a final concentration of allantoic fluid of 1/32 was used, and for the WS strain a concentration of 1/12. The inhibition titrations were set up as described under Methods, adding each virus to dilutions of each of the four sera. The results are recorded in Table IV.

In examining the antigenic relationships shown by this inhibition test it should be noted that each serum inhibited the agglutination by its homologous virus to approximately the same dilution (3000 to 6000). The agglutination of red cells by the Lee virus suspensions was not inhibited by any of the heterologous sera, nor did the Lee antiserum significantly inhibit the reaction due to any of the heterologous viruses. The PR8, the WS, and the swine influenza viruses all showed some interrelationship by this method, and of these the PR8 and the WS showed the greatest similarity. Both the WS and the PR8 sera gave the higher titer with the homologous virus and a four to six times lower titer with the heterologous virus. Swine virus appeared more closely related to the WS strain than to the PR8 strain, both when swine antiserum was tested against PR8 and WS virus, and when PR8 and WS antisera were tested against swine virus.

Neutralization tests in mice were done with these same sera and virus preparations in order to compare the *in vitro* results with one of the generally accepted procedures for the demonstration of antigenic relationships. Approximately 30 fifty per cent mortality doses of each virus were used for the test. The neutralization titers obtained are shown in the last column of Table IV. An interpretation of the *in vivo* results yields essentially the same conclusions about the antigenic relationships of these strains as were obtained from the inhibition test. The only qualitative exception was that the PR8 serum had a higher titer than the WS serum when tested with swine virus in mice, while the reverse was true with these sera against swine virus in the *in vitro* test.

*Agglutination Inhibition Titrations with Human Sera*—Although we have previously reported the demonstration of a rise in agglutination inhibition titer in serum taken from a patient during convalescence from influenza A, it was considered necessary to ascertain how constant this finding would be in a large series of cases.

Forty-four pairs of acute and convalescent sera from cases of influenza A were used. Half the sera were from an institutional epidemic occurring during the winter of 1938-39 (10), and the remainder were from institutional epidemics in Alabama in the winter of 1940-41 (11). The convalescent serum from each patient had a mouse neutralization titer at least four times as high as that of the acute phase serum, when tested with PR8 virus. For the *in vitro* test twofold dilutions of serum were made in saline, beginning with a final serum dilution of 1/8. A final dilution of 1/64 allantoic



fluid, containing PR8 virus, was used. This concentration of allantoic fluid was four times the amount which causes two plus agglutination in an agglutination titration. In every case the titer of the convalescent serum was at least two, and usually four or more, times higher than the titer of the acute serum.

Similar tests were run on sera from individuals who had been vaccinated with a complex influenza vaccine which contained formalinized PR8 virus (12). Sera were taken before and 2 weeks after vaccination. Fifty-five pairs of sera were tested. Each serum was titered by means of the mouse neutralization test, and in every case the postvaccination serum showed at least a twofold rise in neutralizing antibodies against PR8 virus. When these sera were tested *in vitro*, a corresponding rise in inhibition titer following vaccination was demonstrated in every case.

Pairs of serum from fourteen normal individuals obtained at a 1-year interval were included in this experiment. None of the subjects gave any history suggestive of

TABLE V

*Serum Inhibition Titrations on an Immune Ferret Serum Using Different Quantities of Virus*

Dilution of allantoic fluid	Dilution of serum*									Virus control
	1 256	1 512	1 1 024	1 2 048	1 4 096	1 8 192	1 16 000	1 32 000	1 64 000	
1 4	0	±	++	++++	++++	++++	++++	++++	++++	++++
1 8	0	0	±	+++	++++	++++	++++	++++	++++	++++
1 16	0	0	0	±	+++	++++	++++	++++	++++	++++
1 32	0	0	0	0	±	++	++++	++++	++++	++++
1 64	0	0	0	0	0	±	++	+++	++++	++++
1 128	0	0	0	0	0	0	±	++	+++	+++
1 256	0	0	0	0	0	0	0	±	±	++
1 512	0	0	0	0	0	0	0	0	0	0
1 1 024	0	0	0	0	0	0	0	0	0	0

\* All serum dilutions were made in normal horse serum plus saline, so that the final concentration of serum (normal plus immune) was 1/8 in every tube.

influenza during the intervening period, and none of the pairs of sera showed any difference in the virus neutralization titer. There was likewise no demonstrable difference between the inhibition titers of each of the pairs when tested by the *in vitro* technique.

The foregoing experiments, both with ferret and with human sera, demonstrate a consistent qualitative parallelism between neutralization titer in mice and agglutination inhibition titer *in vitro*. Before attempting to demonstrate a more quantitative correlation between the results of the two tests it was considered necessary to investigate the variables entering into the *in vitro* titration in order to find out what precautions are essential to obtain reproducible results.

*Factors Affecting the Results of the Inhibition Test*—In the following series of experiments inhibition tests were performed with a PR8 ferret serum and its homologous virus. In each experiment one variable was introduced into the titrations, in order to see what the effect on the inhibition end point of the serum would be.

In the experiment shown in Table V the ferret immune serum was titrated with a number of different concentrations of the homologous virus. With only minor variations the serum inhibition end points obtained with different quantities of virus were in simple inverse proportion to the amount of virus used in the test. This simple relationship between the amount of virus used and the end point obtained makes it very convenient and easy to compare inhibition tests where different amounts of virus were used. The theoretical implications of this experiment will be more fully considered later.

In another experiment a number of titrations were done on the same serum using different concentrations of chicken red cells for the tests, the results of which are shown in Table VI. While it was difficult to make comparable readings in tests in which there was such a wide variation in red cell concentration, nevertheless it was obvious that the end point decreased as the concentration

TABLE VI

*Serum Inhibition Titrations on an Immune Ferret Serum Using Different Quantities of Cells*

Final cell concentration	Dilution of serum						Virus control	Red cell control
	1 256	1 512	1 1,024	1 2,048	1 4,096	1 8,192	1 16,000	
<i>per cent</i>								
4 0*	0	0	0	0	±	+++	+++++	0
2 0	0	0	0	0	+	+++	+++++	0
1 0	0	0	0	±	+	+++++	+++++	0
0 5	0	0	0	+	+	+++++	+++++	0
0 25	0	0	+	++	++	+++++	+++++	0
0 12	0	±	±	++	++	++	++	0

\* There were 360,000 red cells per c. mm. in the 4 per cent concentration.

of cells used decreased. In this test it was found that by far the most satisfactory concentration of cells for ease in reading the tests was the final 1 per cent concentration used throughout the other experiments in this paper.

Duplicate serum inhibition tests were run simultaneously at 37°C and at 27°C with no obvious difference in end point. Although a wider variation in temperatures produced definite changes in the end points, the ordinary changes in room temperature were not sufficient to alter the results significantly.

Duplicate titrations were done with fifteen human sera (high and low titer) and one ferret serum, using six different lots of red cells. Each lot of red cells was prepared separately, and the various lots were stored at 4°C for from 1 to 6 days before use. There was no systematic tendency of any lot of cells to give high or low results with the various sera. The length of storage apparently had no effect on their agglutinability. In general, duplicate titrations of a given serum gave the same result. In 25 per cent of the tests there was a variation in end point of one-half dilution, and very occasionally there was a variation of a full dilution. From these data it was evident that the use of

different lots of cells was not a serious source of error in the test if the cells had been prepared in a uniform manner

One factor of considerable importance in obtaining uniform results with the test is the length of time between the addition of red cells and the final shaking for thorough mixing. When the tubes of a serum titration were shaken immediately following the addition of cells, the titer obtained was definitely lower than that of a duplicate titration, when the tubes were shaken 5 minutes after adding the cells. In some of the experiments reported here the cells were added with an automatic pipetting machine, which delivered the suspension with such force that sufficient mixing took place at once.

Of some importance also was the question of the length of time necessary for the virus-antibody reaction to take place after serum and allantoic fluid had been mixed together. A number of titrations of an immune ferret serum were done. In each case the red cells were added after the virus and serum had stood mixed together for different intervals. Whether the cells were added immediately after adding virus to the dilutions, or whether the virus-serum mixture was allowed to stand for  $\frac{1}{2}$  hour before adding the cells, the end point was the same. This rapid interaction between virus and serum obviates any necessity of incubating these two reagents together for any fixed period in performing the inhibition tests

The preceding experiments emphasize the fact that the serum inhibition test can be performed in a fairly simple manner, without elaborate equipment or precautions, and that under these conditions quite reproducible results may be obtained.

*Quantitative Correlation between Virus Neutralization and Agglutination Inhibition Titers of Serum*—After it had been shown that the *in vitro* test gave results which were qualitatively similar to those obtained with the mouse neutralization test and that the results were reproducible, the next step was to see how the serum inhibition titer was related quantitatively to the virus neutralization titer on widely different sera.

The sera used were from sixteen persons acutely ill with influenza A, from twenty-one convalescent from influenza A, from twenty-two normal individuals, and from thirty-one who had been vaccinated 2 weeks previously with a complex chick embryo influenza vaccine. Mouse neutralization tests were done on all these sera, using 200 lethal doses of PR8 mouse passage virus, and the sera were diluted in twofold steps. The *in vitro* tests were done with a 1:64 dilution of allantoic fluid containing PR8 virus. The two plus end point of this same fluid in an agglutination titration was 1:256. The end points obtained in the inhibition tests were plotted against the neutralizing capacity as calculated from the mouse neutralization end points (2).

The results are recorded in Fig. 1, in which it can be seen that the points tend to fall along a straight band. On the whole, the correlation is fairly good between the two methods of measurement over a wide range of antibody levels.

and there are no widely discrepant points. The width of the band can be accounted for by the errors in the tests, especially the mouse neutralization test.

This correlation is more significant when one considers that the sera were from four groups of individuals who had had widely differing experience with influenza virus, and yet there is no systematic deviation or scattering of any

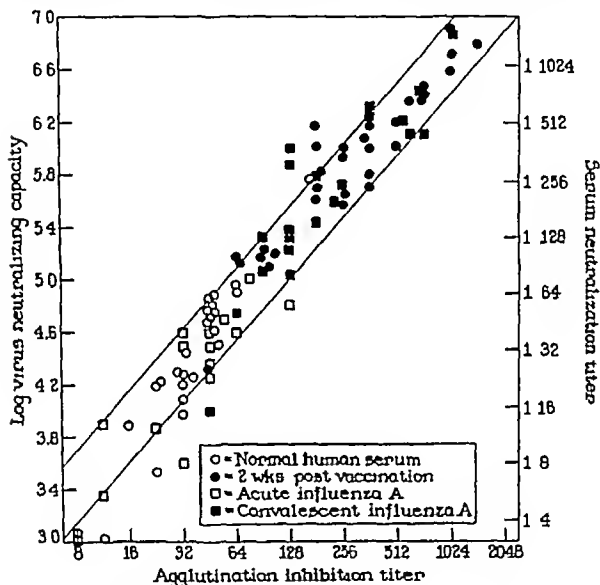


FIG. 1. Correlation of serum inhibition titer with virus-neutralizing capacity of various human sera.

of these groups. The evidence contained in this figure is the best we have obtained so far that the *in vitro* test measures either neutralizing antibodies or something which fairly consistently parallels neutralizing antibodies.

#### DISCUSSION

The advantages of the agglutination tests over mouse tests for influenza virus and influenza antibody titrations are sufficiently clear so that detailed discussion seems unnecessary. While the agglutination titer of a fresh virus suspension shows a fair correlation with the mouse infective titer in the tests we have

recorded, much more work will be necessary to show what the agglutination titer actually measures. In any case, it is a measurement of a new quality of virus suspensions and as such merits further study. The serum inhibition titrations clearly measure influenza antibodies, and from the quantitative results obtained it seems that the test may very likely measure neutralizing antibodies. The only other *in vitro* test described for measuring influenza antibodies is the complement fixation test. While no direct comparisons have been made between the results of this test and the inhibition test, the outstanding advantage of the latter is its ease of performance and standardization.

If these agglutination tests should come into general use, they would be of value in comparing results from different laboratories, provided some sort of standard procedure were used. Based on our present experience, the procedures outlined under Methods seem to be a satisfactory starting point. For serum titrations it would be necessary to state only the number of agglutination units used for the test. We have generally used four times the amount of virus necessary to cause two plus agglutination. All sera should be heated to 56°C for 30 minutes before use. This was not done with the human sera in the experiments reported here, but it has been found since these tests were performed that such heating lowers the inhibition end point of low titer human serum but does not affect the end point of high titer serum. Heating probably inactivates a "normal" inhibitory substance present in such sera.

The fact that eggs inoculated with a number of different influenza virus strains yield allantoic fluids of approximately the same agglutination titer is of some theoretical interest. A number of other strains, besides those employed in the present work, have been cultivated in eggs, and all strains so far tested have shown this same constancy in titration end point by agglutination. This similarity in end point suggests two things: (1) that different strains of influenza virus, when grown in eggs, reach approximately the same virus particle concentration in allantoic fluid, and (2) that the individual virus particles of different strains of virus have the same capacity, or nearly so, to agglutinate red cells. If the second assumption is correct, then the agglutination titration method is a simple way of determining the relative number of particles in suspensions of different strains, independently of pathogenicity, something mouse titration fails to tell. In any case, the test provides a method for studying immunologically and in other ways strains which have not been adapted to mice.

The results of the serum inhibition titrations, using different amounts of virus, show that the same amount of serum inhibits agglutination by a constant amount of virus, regardless of the volume in which the reaction takes place, at least over a considerable range of dilution. This result is in keeping with the classical work on antigen-antibody reactions of Dean and Webb (13), which

showed that the optimal proportions point for antigen antibody reactions was the same, regardless of the volume in which the reaction was carried out. This would tend to show that influenza virus-antibody reactions are the same as other antigen antibody reactions, at least in this respect.

This result, however, is in apparent conflict with those of Horsfall (2) on the shift in serum neutralization end point in mice, where different amounts of virus are used in the test. Horsfall found that if it took  $x$  cc. of serum to neutralize a certain quantity of virus, it took  $x/5$  cc. to neutralize one-tenth as much virus. In the mouse test the serum becomes less efficient on dilution. Since the reasons for the discrepancy are not clear, it will suffice to point out that the mouse test is a very complicated test and involves the interplay of many forces over a period of about 10 days, while the *in vitro* test is relatively simple. Because of the complexity of the mouse test, it seems probable that the agglutination inhibition test gives a more accurate picture of the *in vitro* combining ratios of virus and antibody.

#### SUMMARY

- 1 The agglutination titer for chicken red cells of freshly prepared or carefully stored suspensions of PR8 influenza virus, that is to say virus of maximum pathogenicity, was found to be proportional to the mouse lethal titer of the same preparations.

- 2 The agglutination titer of infected allantoic fluid procured in a standard way is relatively constant, regardless of the influenza strain used and its pathogenicity for mice.

- 3 Virus preparations inactivated by heat or storage may retain their agglutinating power.

- 4 Certain animal sera contain a partially heat labile factor which, in low dilution, inhibits the agglutination of chicken red cells by influenza A and influenza B viruses.

- 5 The agglutination inhibition test, using ferret and human sera, gives qualitative data regarding influenza antibodies which are similar to the information obtained on the same sera by means of the virus neutralization test.

- 6 There is a definite relationship between the agglutination inhibition titer and the virus neutralization titer of a serum. On a logarithmic scale of both variables, this relationship is essentially linear within the range investigated.

- 7 The agglutination inhibition titer of immune ferret serum is inversely proportional to the amount of virus used in the test.

Since this paper went to press, McClelland and Hare (14) have published results confirming the work in our earlier publication (1) on the adsorption of influenza virus on red cells and the use of agglutination for measuring influenza antibodies.

## BIBLIOGRAPHY

- 1 Hirst, G K., *Science*, 1941, 94, 22
- 2 Horsfall, F L , Jr , *J Exp Med* , 1939, 70, 209
- 3 Francis, T , Jr , *Science*, 1940, 92, 405
- 4 Magill, T P , *Proc Soc Exp Biol and Med* , 1940, 45, 162
- 5 Smith, W , and Andrewes, C H , *Brit J Exp Path* , 1938, 19, 293
- 6 Magill, T P , and Francis, T , Jr , *Brit J Exp Path* , 1938, 19, 273
- 7 Francis, T , Jr , and Magill, T P , *Brit J Exp Path* , 1938, 19, 284
- 8 Francis, T , Jr , and Shope, R. E , *J Exp Med* , 1936, 63, 645
- 9 Smith, W , Andrewes, C H , and Laidlaw, P P , *Brit J Exp Path* , 1935, 16, 291
- 10 Horsfall, F L , Jr , Hahn, R G , and Rickard, E R , *J Clin Inv* , 1940, 19, 379
- 11 Lennette, E H , Rickard, E R , Hirst, G K., and Horsfall, F L , Jr , *Pub Health Rep , U S P H S* , 1941, 66, 1777
- 12 Horsfall, F L , Jr , Lennette, E H , and Rickard, E R , *J Exp Med* , 1941, 73, 335
- 13 Dean, H. R , and Webb, R A , *J Path and Bact* , 1926, 29, 473
- 14 McClelland, L , and Hare, R , *Canad Pub Health J* , 1941, 32, 530

## DEMONSTRATION OF AGGLUTININS FOR *BARTONELLA* *BACILLIFORMIS*

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Human bartonellosis, known as Carrion's disease, manifests itself in two distinct phases. The first phase, Oroya fever, is a severe hemolytic anemia, the result of the invasion of the blood stream by the organism, *Bartonella bacilliformis*. Blood cultures are strongly positive at this stage of the disease, and the red blood cells as well as the cells of the reticulo-endothelial system, are heavily parasitized by *Bartonella*. The second phase, verruga peruana, is characterized by the appearance of the typical cutaneous eruption from the nodules of which *B. bacilliformis* may be recovered. Bartonellosis is endemic in certain regions of Peru and has more recently been found to be so in Colombia and Ecuador. In these endemic regions, the second stage (verruca) is more commonly encountered. Less frequently, the anemic stage, when very severe, ends fatally before the development of the eruption. A large percentage of the native population of the endemic zones in Peru have had some form of bartonellosis, mild or severe, and are able to live there without further clinical evidence of infection. Second attacks of acute fever without the eruption are apparently unusual but second attacks of verruga with minimal febrile illness are not rare. From these facts, it is evident that in most of those individuals who have contracted bartonellosis at least once a definite and long lasting immunity develops against the infection. This immunity on the part of the natives is in strong contrast to the often fatal infection which develops in individuals from non-endemic zones who spend but a few nights in the endemic zones without adequate protection against the night flying sandfly vector. Somewhere in between these two extremes of complete immunity on the one hand and complete susceptibility on the other if one

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speculates in terms of immunology, must lie the so called carriers, thought by Weinman and Pinkerton (1) to represent a possible reservoir of infection. These authors have estimated the number of such individuals in one locality of the endemic region of Peru at about 5 to 10 per cent of the total population. They show no outward sign of infection, but *B. bacilliformis* may be recovered from their blood, which may or may not show a slight anemia. It is evident from the foregoing rather empirical facts that the fundamental immunological pattern of human bartonellosis remains still to be worked out. The present report is a step toward the solution of this complex problem.

The work which follows deals with the production and the demonstration of specific agglutinins for *B. bacilliformis* in rabbits, and their demonstration in the sera of human beings with bartonellosis. In the literature on Carrion's disease, the possibility of agglutinating *B. bacilliformis* with specific sera of one sort or another has been considered from time to time by various authors (2-7). In no instance is there any indication of clear-cut experiments on this aspect of the problem, and in all cases the only tangible conclusion that has been reached is that any demonstration of agglutinins is handicapped by the difficulties encountered in preparing suspensions of the organism suitable for use as an antigen.

#### *Materials and Methods*

*Media and Cultivation of Bartonella*—Heretofore, the only media that have yielded fairly satisfactory growth have been ordinary blood agar and the semisolid medium of Noguchi and Battistini (3) originally designed for the cultivation of *Leptospira*. The former medium yields colonies of tightly packed organisms on the slant, with many of the colonies embedded in agar, the latter medium a variable and diffuse growth, with aggregates of smaller satellite granules, in the upper 1 to 2 cm. of the medium. Both types of medium present obstacles to the preparation of a homogeneous suspension, chief among which is that resulting from the presence of agar, from which the organisms are inseparable. Two types of medium recently developed by Geiman in Boston (8) have effectively removed these obstacles.

The first is a solid medium. Special base agar is made with 2 per cent shredded agar, 2 per cent tryptone or proteose peptone, 0.5 per cent sodium chloride, in distilled water. The medium, as finally used, is composed of 75 per cent base agar, adjusted to pH 7.6-7.8 and cooled to 45°C., and 25 per cent fresh rabbit or sheep serum, or defibrinated whole blood. To the whole medium, a small amount (0.2 per cent of the total volume of medium) of an ascorbic acid glutathione solution is added. This medium gives a profuse growth, which follows the streak of the loop on the slant and becomes grossly visible in 24 to 48 hours, reaching a maximum in 10 to 14 days. The optimal temperature for incubation is 28°C. The growth may be easily scraped from the surface, and collected from the water of condensation at the bottom of the tube.

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The second is a liquid medium. It is composed of three parts of a 1 per cent solution of tryptone adjusted to pH 7.6-7.8 to one part fresh rabbit serum and to the whole medium is added a small amount (0.2 per cent of the total volume of medium) of the ascorbic acid glutathione solution. Growth becomes visible as a finely divided sediment within 24 to 48 hours and reaches a peak on the 10th day when incubated at 28°C. It has been found by Geiman that maximum growth takes place at the bottom of the container when the depth of this medium is from 0.5 to 0.75 cm. Small (50 cc.) Erlenmeyer flasks are used, to afford as large an area as possible at this optimal depth for the growth which takes place on the bottom of the flask. The present writer has found that ordinary test tubes (14 cm.  $\times$  2 cm.), bent to resemble a hockey stick in shape with the short arm at the open end of the tube, serve better than Erlenmeyer flasks for the cultivation of *Bartonella*. The tubes are stored horizontally, the open end directed upward to prevent outflow of the medium with which the tubes are filled to half of their horizontal depth, i.e. 0.5 to 0.75 cm. Growth takes place along the bottom of the converted test tube and the yield is about equal to that obtained with the flasks. There is further the added advantage of convenience and less danger of contamination than that encountered with the flasks.

*Preparation of Antigen*—The organisms harvested from both types of medium when washed two or three times in normal saline and resuspended in saline buffered to pH 8.2-8.4, constitute a homogeneous antigen admirably suited for agglutination tests. It has been found more recently that clumps of organisms harvested in a similar manner but stored as a coarse suspension in normal unbuffered saline can after about a week of such storage be easily emulsified by churning with a capillary pipette (9). The coarser particles in either type of suspension are allowed to settle or are thrown down by slow centrifugation. In both cases dark field examination reveals a fairly regular distribution of single organisms with occasional clumps of never more than 5 to 10 (Fig. 1). These occasional clumps are just visible with a 10 or 14 power hand lens.

*Technique of Agglutination Test*—The technique of the test for agglutinins has been designed to allow rigid economy of materials and at the same time permit accurate gradation of titre. Small fermentation tubes (7.5 cm.  $\times$  0.75 cm.) are used and the total final volume confined to about 0.1 cc. The tubes after proper serial dilution of the sera and the addition of the antigen are incubated for 4 to 6 hours at 40°C and are then read with the aid of a 10-14  $\times$  hand lens and after 24 hours on ice they are again read. In the strongly positive tubes, there is a heavy and tightly coherent precipitate with clear supernatant liquid. Dark field examination (Fig. 2) reveals a definite heavy clumping of the single organisms and the small groups of organisms seen in the control (Fig. 1). In the negative and the control tubes when examined with the hand lens there is over more than a very slight sediment, which is easily dispersed.

*Immunization of Rabbits*—To obtain specific agglutinins a series of rabbits was immunized by repeated injections of living *B. bacilliformis* into the marginal vein of the ear. The organisms from a tube of liquid culture after 10 days to 2 weeks incubation or a week's growth from a solid slant washed twice with saline, was given every 5th day over a period of 60 days each animal having received 12 to 13 inocula.

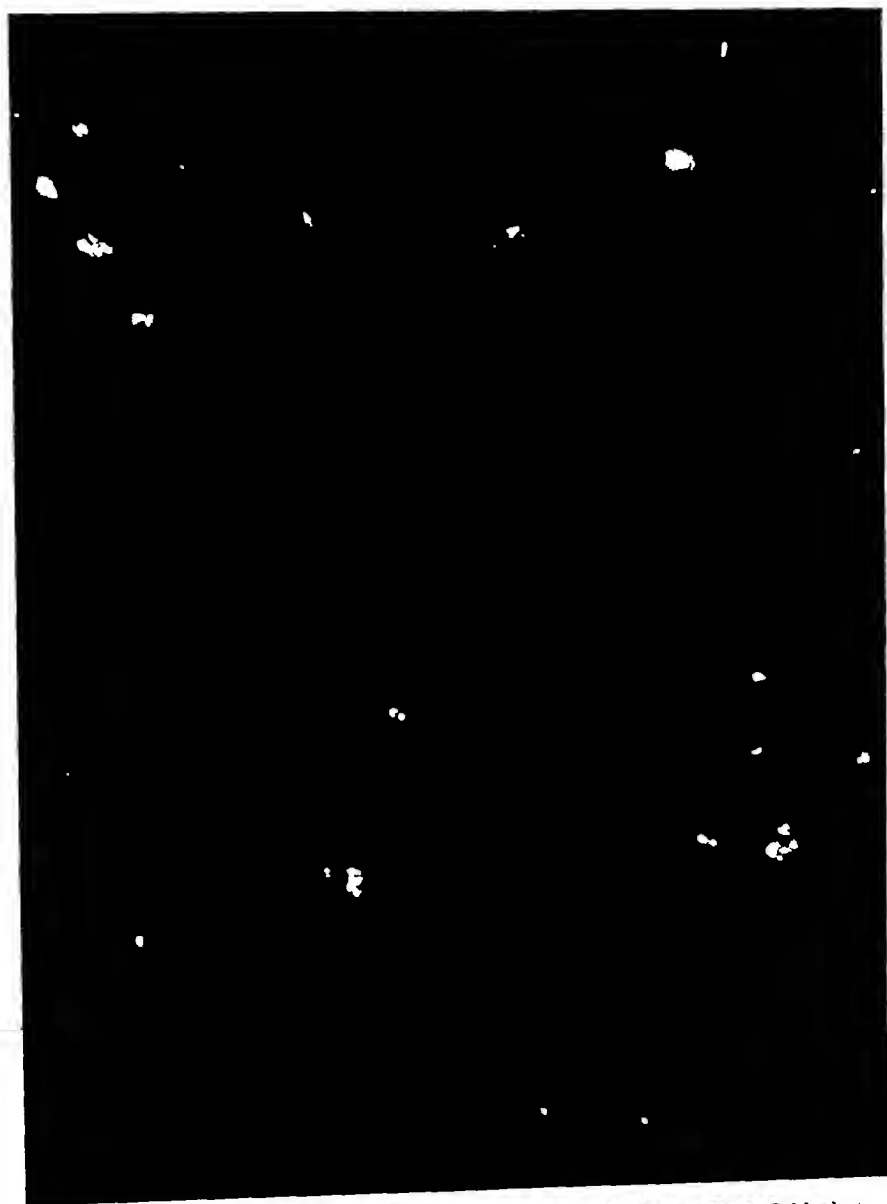


FIG 1 Suspension of *Bartonella bacilliformis* in normal saline Dark field photo micrograph  $\times$  about 4000, oil immersion

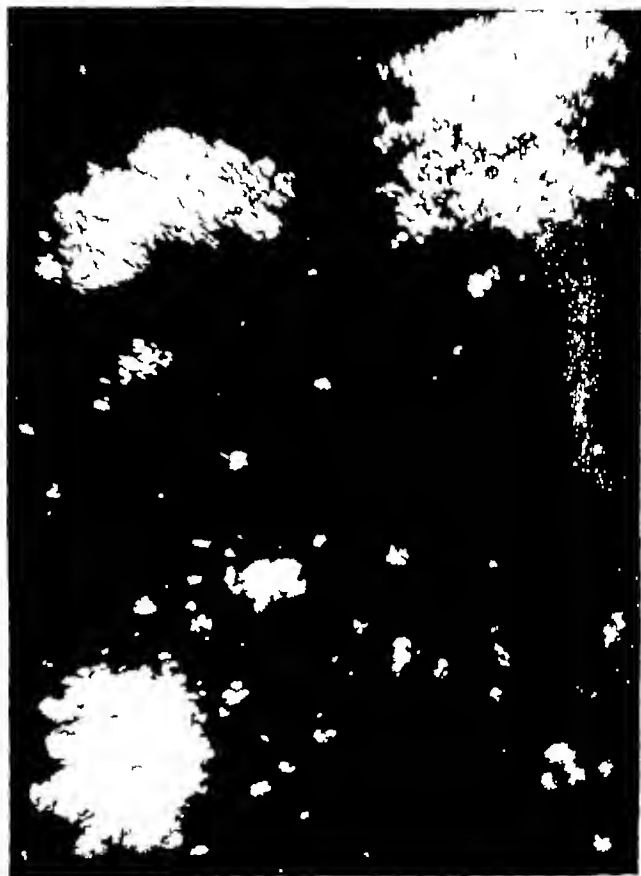


FIG 2 Agglutination of *Bartonella bacilliformis* by serum of immunized rabbit 1 in dilution of 1:640. Dark field photomicrograph.  $\times$  about 4000, oil immersion.

tions in all at the end of that time. Two rabbits were treated in a manner different from the others. One of these (rabbit 1) was inoculated every 3rd or 4th day with the material and by the method described above, 15 inoculations having been given at the end of 50 days. The other rabbit (rabbit 2) had been splenectomized, and into the anterior chamber of both eyes, chopped rabbit embryo had been successfully implanted. *B. bacilliformis* was then injected into both anterior chambers, and given in large quantity intratracheally, in an attempt to produce some tangible evidence of pathogenic effect. 2 weeks after the intratracheal and intraocular inoculations, one eye, which was then aseptically removed, showed a marked pannus formation, with ingrowth of vessels into the cornea, and the other eye showed nothing. Cultures taken from the implanted tissue and the aqueous humor of the enucleated eye showed a heavy growth of *B. bacilliformis*, but blood cultures were negative. Serum for agglutination was taken at this time. At no time did any of the animals, no matter in what way they had been inoculated, show any signs of systemic reaction which could have been interpreted as having resulted from the inoculation.

### *Results with Rabbit Sera*

The results obtained in testing the sera of these rabbits for agglutinins by the method described are shown in Table I. In the case of rabbits 1 and 3, in order to determine the rate at which antibodies might be appearing, serum was taken after one-half the total projected number of inoculations had been given, and showed a moderate titre of agglutinins. The titre as determined after all inoculations had been given was proportionately higher in all cases. The definitely higher titre of rabbit 1 as compared with that of rabbits 3, 4, and 5 might be explained by the larger number of inoculations given at shorter intervals to rabbit 1 (15 inoculations in 50 days as opposed to 12 in 60 days), although this difference in titre may only be an indication of wide variation in the strength of response among individual animals. There was in the case of rabbits 1, 3, and 4 a marked falling-off of titre at the end of 1 month after the last inoculation. Rabbit 5 showed a somewhat higher titre of agglutinins than did the other two, and maintained this higher titre longer than the latter, although there was a slight but definite falling-off at the end of 1 month after the last inoculation. In the case of rabbit 2 the titre of agglutinins obtained as a result of the simultaneous intraocular and intratracheal inoculations described above, lies midway between that of rabbit 1 and those of rabbits 3 and 4. There is no indication, in this single experiment (rabbit 2), as to which method of inoculation may have resulted in so high a titre, or whether both were necessary to produce it. The fact that cultures made from the eye fluid and the infected implanted embryonic tissue were strongly positive after 2 weeks suggests the possibility that these two foci were a source of continuous stimulation to the production of antibodies by the host.

*Results with Human Sera*

Table II summarizes the findings with a small group of human sera. Two cases in which the anemic manifestation had been minimal and the verrucous

TABLE I  
*Agglutination of Bartonella bacilliformis by Serum of Immunized Rabbits*

Rabbit	Time	Final dilution of serum						
		1:10	1:20	1:40	1:80	1:160	1:320	1:640
1	Before immunization	—	—	—	—	—	—	—
	After 7 intravenous inoculations in 22 days	4+	4+	4+	4+	2+	—	—
	5 days after last of 15 intravenous inoculations given over 50 days	4+	4+	4+	4+	4+	4+	3+
	28 days after last intravenous inoculation	4+	4+	4+	3+	2+	—	—
2	Before intratracheal and intraocular inoculation	—	—	—	—	—	—	—
	13 days after intratracheal and intraocular inoculation	4+	4+	3+	3+	+	—	—
	34 days after intratracheal and intraocular inoculation	4+	4+	4+	4+	3+	3+	—
3	Before immunization	—	—	—	—	—	—	—
	After 7 intravenous inoculations in 33 days	2+	2+	2+	+	+	—	—
	3 days after last of 13 intravenous inoculations given over 60 days	4+	4+	4+	3+	2+	—	—
	36 days after last intravenous inoculation	4+	4+	4+	+	—	—	—
4	Before immunization	—	—	—	—	—	—	—
	5 days after last of 12 intravenous inoculations given over 60 days	4+	4+	3+	2+	2+	+	—
	37 days after last intravenous inoculation	3+	3+	3+	+	—	—	—
5	Before immunization	—	—	—	—	—	—	—
	3 days after last of 13 intravenous inoculations given over 64 days	3+	3+	3+	3+	2+	2+	—
	36 days after last intravenous inoculation	3+	3+	3+	2+	2+	2+	—

4+, heavy coarse precipitate at bottom of tube clear supernatant liquid.

3+ to + gradually decreasing amounts of precipitate but obvious agglutination of suspended organisms when compared with saline and normal serum controls.

— no agglutination

stage more extensive (cases 1 and 5) showed the highest titre of agglutinins, and the two severe cases of Oroya fever (cases 2 and 3) the lowest. Thirteen normal human sera were consistently and entirely negative. Although definite

conclusions cannot be drawn from so small a series of cases, the possibility that the appearance of the eruption is associated with the formation of a demonstrable titre of circulating antibodies may be considered. The development of the eruption is invariably regarded by experienced clinicians as a favorable prognostic sign. The fact that the serum of the so called "immune" (case 6) contained a minimal titre of agglutinins may be analogous to the falling-off of titre noted with the rabbit sera. A satisfactory test for the virulence of the organism concerned (and hence a susceptible laboratory animal) would, of course, be necessary in the final elucidation of the fundamental immunological process involved in human bartonellosis.

TABLE II

*Agglutination of Bartonella bacilliformis with Sera of Patients Suffering or Recovered from Bartonellosis (Carrion's Disease)*

Case	Final dilution of serum			
	1 10	1 20	1 40	1 80
1	2+	+	+	±
2	+	+	—	—
3	+	±	—	—
4	+	—	—	—
5	2+	+	+	±
6	+	±	—	—
Normal human serum*	—	—	—	—

\* Thirteen normal human sera were tested.

4+, heavy coarse precipitate at bottom of tube, clear supernatant liquid

3+ to +, decreasing amounts of precipitate at bottom of tube, but obvious agglutination of suspended organisms when compared with saline and normal serum controls

±, slight but definite agglutination, with no heavy precipitate

—, no precipitate or agglutination

The question of the relationship of *Bartonella* to the organisms of the *Rickettsia* group has also been explored. With this possible connection in view, the six human sera tested for agglutinins for *Bartonella* were also tested with three strains of *Proteus*, after the manner of the Weil-Felix reaction. The results are shown in Table III. The two sera which agglutinated *Bartonella* most strongly also show the highest titres with two of the *Proteus* strains (sera of cases 1 and 5). Although a positive agglutination at a dilution higher than 1 50 is usually considered significant with the Weil-Felix reaction, there are occasional cases without a positive history of typhus whose sera are positive in much higher dilutions. Since, also, the histories of the cases involved herein had not been probed for the possibility of typhus,

no definite conclusions can be drawn as to the meaning of the results obtained with these particular sera. The question becomes even more obscure from lack of knowledge of the distribution of endemic typhus fever in Peru. The only available figure is that of the total number of cases during the year

TABLE III  
*Agglutination of Proteus OX19, OXK, and OX2*

Case	Strain	Final dilution of serum					
		1:8	1:16	1:32	1:64	1:128	1:256
1	Proteus OX19	4+	4+	4+	3+	2+	+
	Proteus OXK	3+	2+	2+	—	—	—
	Proteus OX2	4+	4+	2+	+	—	—
2	Proteus OX19	3+	2+	2+	+	—	—
	Proteus OXK	2+	—	—	—	—	—
	Proteus OX2	3+	2+	+	+	—	—
3	Proteus OX19	4+	3+	2+	+	—	—
	Proteus OXK	3+	2+	+	—	—	—
	Proteus OX2	4+	3+	+	—	—	—
4	Proteus OX19	2+	+	—	—	—	—
	Proteus OXK	4+	3+	+	—	—	—
	Proteus OX2	2+	—	—	—	—	—
5	Proteus OX19	4+	4+	3+	3+	+	—
	Proteus OXK	4+	4+	2+	+	—	—
	Proteus OX2	4+	4+	3+	2+	+	—
6	Proteus OX19	—	—	—	—	—	—
	Proteus OXK	3+	2+	2+	—	—	—
	Proteus OX2	+	—	—	—	—	—
Normal human serum	Proteus OX19	3+	+	—	—	—	—
	Proteus OXK	3+	2+	—	—	—	—
	Proteus OX2	3+	2+	+	—	—	—

All saline controls negative. *Bartonella* immune rabbit serum negative with all strains of *Proteus*.

Tubes incubated 4 hours at 40°C.

Legend the same as that for Tables I and II.

1940, January through September, amounting to 667, no geographical allocation being given in the report (10). It is of importance to note, from an immunological point of view, that there was no agglutination of *Proteus* in significant titre by *Bartonella* immune rabbit serum.



*Origin of the Human Sera Represented in Tables II and III, with a Brief Description of Each Case*

*Case 1*—Serum was taken during the 3rd month of a third mild attack of bartonellosis, at which time there was slight anemia, and extensive eruption. Blood cultures were negative, having been positive during the 1st month of the recurring disease, during which time there had been no eruption.

*Case 2*—Serum was taken on the 12th day of the disease. There was severe anemia (red blood cell count 1.7 million), blood cultures were positive, and *Bartonella* were found in the blood film. Death occurred on the 15th day of the disease.

*Case 3*—Serum was taken on the 16th day of the disease. There was severe anemia (red blood cell count 1.0 million), blood cultures were positive, and *Bartonella* were found in the blood film. There was subsequent recovery, no *Bartonella* having been found in the blood films after the 26th day, at which time blood cultures also became negative.

*Case 4*—Serum was taken during the 2nd month of a mild attack of verruga peruana, the eruption having appeared after 1 month of symptoms. Laboratory data were not available, and the history not precisely known. The eruption, however, was definitely that of verruga, but was confined to one large "mulaire" type of lesion on the left shin.

*Case 5*—Serum was taken during the 2nd month of an attack of verruga peruana. The appearance of the rash was preceded by symptoms of malaise and joint pains. Laboratory data were not available, and the history not precisely known. The eruption, however, was definitely that of verruga, and was far more extensive than that of case 4.

*Case 6*—This was a so called "immune," who, having had verruga in childhood, has remained free from signs and symptoms of bartonellosis all of his life (30-odd years) in spite of frequent and prolonged sojourns in the areas where Oroya fever and verruga peruana are endemic.

#### DISCUSSION

The fact that it is possible to produce circulating antibodies in rabbits, and that circulating antibodies may be demonstrated in human beings with bartonellosis makes it certain that at some stage during the course of an infection with *B. bacilliformis* there is a measurable immunological response on the part of the host. This response, now proven by the formation of agglutinins, can be used as a basis for further investigation with three principal objectives: 1) A clarification of the fundamental immunological sequence in human bartonellosis, 2) an evaluation of the properties of immune sera in the therapy of Oroya fever and of the effectiveness of vaccines in the prophylaxis of non-immune individuals, and 3) an elucidation of the antigenic and immunological characteristics of *B. bacilliformis*. With regard to the latter problem, preliminary studies have already been undertaken to determine possible immunological variations among *Bartonella* isolated from different sources and localities. These experiments have indicated that no immunological differ-

ences between such strains can be demonstrated by the agglutination test, cross-agglutination between four Peruvian and two Colombian strains by homologous and heterologous sera to almost equal titre having been accomplished

#### SUMMARY

1 Methods of preparing a satisfactory antigen having been developed, a technique for performing an agglutination test with *B bacilliformis* is made available

2 As a result of repeated intravenous injection of living cultures of *B bacilliformis* at short intervals, rabbits have been found to produce a high titre of specific agglutinins which, under the conditions obtaining in the present series of experiments, begins to decline after about one month following the last inoculation

3 Sera from six cases of bartonellosis in different stages of its several manifestations have been shown by the agglutination test to contain a low but definite titre of circulating antibody

4 Several of these same sera have been shown to contain as well a significantly high titre of agglutinins for three strains of *Proteus*. No definite conclusions can be drawn from this phenomenon since the case histories had not been probed for the possibility of typhus fever, and since the relatively high titres obtained with a few of the present sera may very well fall within the extremes of normal serum titres.

#### BIBLIOGRAPHY

- 1 Weinman, D and Pinkerton H. *Proc. Soc. Exp Biol and Med*, 1937, 37, 596.
- 2 Battistini, T S, *Ann Fac. Med Lima*, 1925 Num Ext. Oct. 1, 26
- 3 Noguchi H and Battistini T S *J Exp Med* 1926 48, 851
- 4 Noguchi, H. *J Exp Med* 1927 45, 175 1928 47, 219
- 5 Sorge G *Arch Farm. Sper*, 1929 48, 53
- 6 Aldana G L *Crón méd*, Lima 1929 48, 235
- 7 Samper, B and Montoya J A, *Rev Fac Med Bogota* 1940, 9, 197
- 8 Geiman, Q M. *Proc Soc Exp Biol and Med* 1941 47, 329
- 9 Geiman Q M., personal communication.
- 10 *Pub Health Rep U S P H S* 1940 55, 2249



## THE EFFECT OF SULFAPYRIDINE UPON THE DEVELOPMENT OF IMMUNITY TO PNEUMOCOCCUS IN RABBITS

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Although the antibacterial action of sulfonamide compounds upon certain pathogenic microorganisms is now generally recognized, the effect of these drugs upon the immunological response of the animal or human host has not been completely elucidated. In view of the value of sulfonamides in the therapy of pneumonia and other diseases caused by pneumococci and because of the essential contribution of immunity to recovery from such infections, it seemed desirable to investigate further the action of sulfapyridine upon the immune processes.

In response to the antigenic stimulus of pneumococcus the tissues of man and certain animals are capable of elaborating type specific antibodies which circulate in the blood and can be determined by the appropriate techniques. In experimental animals it is also possible to recognize the occurrence of active immunity as indicated by increased resistance to homologous infection which may be present before and may persist after the period when circulating antibodies are detectable. In the process of spontaneous recovery from pneumococcal infection disposal of the invading microorganisms by the phagocytic cells cannot be accomplished without the development of a specific immune response.

The sulfonamide compounds exert a direct bacteriostatic effect upon various microorganisms. For these drugs to be effective therapeutically, however, the participation of specific humoral and cellular reactions of the host are essential requirements. The question of whether, in addition to their direct actions upon the bacteria, these compounds may not also exert an effect upon the defense mechanism of a host has been subjected to both experimental and clinical investigation. It has been demonstrated in mice injected intraperitoneally with pneumococci that the sulfonamide drugs do not affect the mobilization or activity of the phagocytic cells (1, 4). Although no evidence has been produced to show that these drugs stimulate or accelerate the process of antibody formation, the assumption that they exert no effect on the immune mechanism has not been unreservedly accepted.

In 1937 Buttle (2) observed that mice after recovery from infection with *Pneumococcus* Type I following treatment with the benzylidene Schiff's Base of 4,4'

diaminodiphenylsulfone were immune to reinfection with organisms of the homologous type. In the following year Whitby (3) confirmed this observation in mice treated with sulfapyridine. McIntosh and Whitby (4) found that at the end of 1 week mice which had survived 10,000 lethal doses of *Pneumococcus* Type I after oral treatment with sulfapyridine were completely immune to reinfection with a million fatal doses of pneumococci of the homologous type. This immunity was related quantitatively to the infective dose and was type specific. An inoculum of 1 million heat-killed pneumococci stimulated in vaccinated mice a degree of immunity comparable to that induced in mice following recovery under drug therapy from an otherwise fatal infection with 10,000 living pneumococci. In the latter instance the surviving animals on reinoculation were immune to an amount of virulent culture 100-fold greater than that used in the primary infection. The active immunity induced by vaccination or resulting from infection was demonstrable within 3 days. By the 4th or 5th day immunity was usually solid, and on the latter day the sera conferred passive protection on other mice. In the sera of mice immunized with *Eberthella typhosa* agglutinins were demonstrable by the 3rd day and increased in titer between the 4th and 7th days irrespective of whether or not sulfanilamide had been administered. These authors concluded that "the administration of sulphonamide drugs has no stimulating action on the body defenses, nor does such administration affect the quality, quantity, or speed of production of recognized specific antibodies." Experimental confirmation of Whitby's observation was reported in 1939 by Callerio (5) and MacLeod (6). MacLeod compared the survival rate following sulfapyridine therapy with the immune response in untreated animals, employing *Pneumococcus* Type I, a good antigen, and *Pneumococcus* Type III, a relatively poor antigen. He found that in mice infected with  $10^{-2}$  cc of a virulent culture of *Pneumococcus* Type I and treated with sulfapyridine, 95 to 100 per cent survived, whereas in mice similarly treated but infected with Type III pneumococci less than 10 per cent survived. In two groups of untreated mice immunized respectively with comparable doses of heat-killed pneumococci of Types I and III and infected 5 days later with 1,000 fatal doses of a virulent culture of the corresponding type, 95 to 100 per cent of those in the Type I group were immune while none of the Type III mice survived. An apparent correlation was observed not only between the survival rate and the relative antigenicity of the respective types of pneumococci, but also between the differences in the time required for the development of antibodies and the length of time during which it was necessary to continue sulfapyridine treatment. Larson, Bieter, and Levine (7, 8) demonstrated that rabbits which recovered from intradermal infection with *Pneumococcus* Type II following treatment with sulfapyridine were highly resistant to reinfection with the homologous type of organism 30 or more days later.

In the sera of patients with pneumococcal pneumonia the appearance of type specific antibodies at or about the time of spontaneous recovery is a well recognized phenomenon. However, in patients treated with sulfonamide drugs the appearance of these antibodies does not necessarily coincide with the defervescence frequently observed early in the course of illness.

Edwards, Kircher and Thompson (9) tested 26 pneumonia patients treated with sulfapyridine for the development of dermal reactions to homologous type specific capsular polysaccharide as well as for the presence in their sera of type specific agglutinins. They concluded from the results of their observations that the immune responses which occur naturally in the course of untreated pneumonia are not affected by drug therapy.

Wood and Long (10) demonstrated specific protective antibodies in the sera of 10 out of 12 patients with pneumococcal pneumonia who were treated with sulfapyridine. They concluded that the antibody response in patients treated with sulfapyridine is similar to that observed in untreated patients.

Finland, Spring, and Lowell (11) studied the bactericidal power of whole blood as well as the development of homologous type specific agglutinins and mouse protective antibodies in the sera of a large number of patients with pneumococcal pneumonia treated with sulfapyridine. These investigators reported that mouse protective antibodies and agglutinins were rarely demonstrable in patients' blood before the 6th or 7th day although desferescence frequently occurred earlier. They concluded that the antibody response in patients treated with sulfapyridine was comparable in all respects to that observed in spontaneous recovery.

Fox, Rosi and Winters (12) determined the time of appearance of specific antibodies in the sera of 50 adult patients treated with sulfapyridine. In all patients with proven pneumococcal pneumonia type specific agglutinins were demonstrable in the blood at some time in the course of illness. These same authors reported subsequently (13) that in a larger series 90 per cent of the patients developed type specific agglutinins by the end of the 2nd week of illness and that 50 per cent of those tested gave true positive skin reactions to the homologous type specific polysaccharide.

Kneeland and Mullikin (14) tested the sera of 19 patients with pneumonia who were treated with sulfapyridine. They observed that positive precipitin reactions to the homologous capsular polysaccharide appeared in the sera of only four of their patients upon recovery. In a subsequent paper these authors (15) reported that type specific precipitins were detectable in the sera of only 8 of 30 sulfapyridine-treated patients as compared with 16 of 21 patients treated with sulfathiazole. They suggested that sulfapyridine by its action upon the invading microorganism diminishes the stimulus to antibody formation whereas sulfathiazole, which they considered a less powerful bactericidal agent, exerts this effect to a lesser degree.

Bukantz and de Gara (16) demonstrated the presence of homologous type specific precipitins during recovery in the sera of nineteen of sixty patients with pneumonia who were treated with sulfapyridine.

In the animal experiments thus far reported, with the exception of those of McIntosh and Whitby, tests for resistance to homologous reinfection have been made at a time when immunity had reached or passed the peak of maximal response. In clinical studies the detection of circulating type specific antibody is necessarily limited by the methods which can be employed. The free circulating antibodies detectable *in vitro* by serological techniques probably repre-

daily from the marginal ear veins. Animals which died were examined at autopsy and cultures were made of the heart's blood.

*Determination of Circulating Antibodies* *Precipitins*—Precipitin tests were carried out using 0.3 cc. respectively of undiluted rabbit serum and a 1:25,000 dilution of the acetylated pneumococcus Type I capsular polysaccharide. After thorough mixing of the contents, the tubes were incubated at 37°C for 2 hours, refrigerated overnight, and read the following morning.

*Agglutinins*—Tests for type specific agglutinins were carried out using serial dilutions of each serum. Formalin-killed cells of *Pneumococcus* Type I, suspended in a volume of saline equal to that of the original culture were employed. To 0.3 cc. of the serum dilutions, 0.3 cc. of antigen was added and after thorough mixing the tubes were incubated at 37°C, refrigerated overnight and read the following morning.

*Mouse Protective Antibodies*—The sera of rabbits before immunization and at intervals of 48, 72, or 96 hours thereafter were tested in mice for protective antibodies by titrating dilutions of culture against a constant amount of serum.

The cultures of *Pneumococcus* Type I (S V-I) used in protection tests were of such virulence that the intraperitoneal injection of  $10^{-5}$  cc invariably proved fatal. The protection test was considered negative if 0.2 cc of serum failed to protect 2 of 3 mice against  $10^{-6}$  cc. of culture. Sera of rabbits which afforded protection to mice infected with  $10^{-6}$  cc (100 M.L.D.) of culture were also tested against  $10^{-5}$  cc. (1000 M.L.D.) Amounts of culture greater than this were not used.

*Blood Levels of Free and Acetylated Sulfapyridine*—Blood drawn at intervals during the period of sulfapyridine administration indicated satisfactory absorption of the drug. The blood levels of free and acetylated sulfapyridine, however, varied greatly in different animals under the same conditions. During the period of administration the highest concentration of free drug noted was 15.0 mg per cent, the lowest 0.5 mg per cent. The highest concentration of the acetylated compound was 71.2 mg per cent, the lowest 4.3 mg per cent. Although the blood level of free sulfapyridine dropped fairly rapidly in the interval between doses and after administration was discontinued, the acetylated form was eliminated much more slowly. In order that there should be little or no sulfapyridine remaining in the blood at the time of intradermal infection it was found necessary to discontinue administration of the drug 24 to 36 hours prior to infection. Determinations made 24 hours before intradermal infection showed that only 9 of the 34 animals still had free circulating sulfapyridine, although at this time the blood of all of the 22 rabbits tested for the acetylated compound showed its presence in amounts ranging from 1.3 to 71.2 mg per cent.

Determinations made immediately before infection upon the blood of 30 immunized rabbits which received sulfapyridine showed the presence of the free drug in 3 instances. The blood of only one of these animals contained a measurable quantity (1.6 mg per cent). On the other hand, the acetylated

compound was present in the blood of 11 out of 26 rabbits immediately before infection. The levels varied between 0.5 mg and 5.7 mg per cent. That these residual amounts of sulfapyridine remaining in the blood at the time of intradermal infection exerted no significant mitigating effect upon the course of the disease is indicated by the following observations. Sulfapyridine was present at the time of intradermal infection in the blood of three of the four treated animals which died. Furthermore, the fatal course of infection in four sulfapyridine treated rabbits which were not immunized, was essentially the same as that in the normal controls. Crystals of acetylated sulfapyridine were found at autopsy in the bladder and renal pelvises of two rabbits which developed overwhelming bacteremia.

*Toxic Effects of Sulfapyridine*—Almost all of the rabbits which received sulfapyridine showed some evidence of intoxication during the course of drug administration. This was manifested by varying degrees of anorexia, weakness, and loss of weight. Sulfapyridine intoxication may have been a contributory factor in the death of one rabbit which was infected 72 hours after immunization and died on the 4th day after a mild illness unaccompanied by bacteremia. Postmortem examination revealed a loss of 300 gm in weight, a minimal skin lesion showing evidence of healing and no gross abnormalities of the organs. Analysis of the bladder urine disclosed the presence of acetylated sulfapyridine in a concentration of 2.5 mg per cent.

It seems evident that the amount of drug used in these experiments was about the maximum that could be tolerated by the animals over the period of administration.

*Effects of Intravenous Injection of Pneumococcal Vaccines*—The intravenous injection of heat killed *Pneumococcus* Type I was frequently followed by an immediate but transient elevation of temperature. No other untoward reactions were noted. The variations of the immune response in sulfapyridine treated and untreated animals at different intervals following immunization are considered later in detail.

*Characteristics of the Disease Produced by Intradermal Infection*—The disease produced in rabbits by the intradermal injection of *Pneumococcus* Type I has been thoroughly described by Goodner (18, 19). The course of the illness in the 26 control animals corresponded closely to his description. The disease was characterized by high sustained fever, extensive dermal lesions, progressive bacteremia, and an invariably fatal termination within 6 days. In immunized rabbits modifications of these findings were progressively more in evidence as the interval between immunization and infection was increased. As a basis for the estimation of active immunity, the effects of infection at different intervals after immunization in rabbits which received sulfapyridine are compared with the reactions of animals to which no drug was given. These data are presented graphically in Text fig. 1.



Hours intervening between immunization and intradermal infection	Received no sulfapyridine				Received sulfapyridine			
	Rab No.	Incidence and duration of fever  T 104° F or over	Incidence and severity of lesions	Incidence, duration and severity of bacteremia No. col./cc. D = died	Rab No.	Incidence and duration of fever  T 104° F or over	Incidence and severity of lesions	Incidence, duration and severity of bacteremia No. col./cc. D = died
48	8-79		++	3000/1 D	8-87		+++	3/0
	8-80		++++	0 0	8-88		+++	6/0
	8-83		++++	50/2	8-90		+++	6/0
	8-84		++++	70/2	8-91		++	0 0
	7 07		+++	3/15 0 0	7 01		+++	228/6 7/2 D
	7-08		++++	6/3 0 0	7 02		+++	33/12 D
	7-09		++++	13/0 0 0	7-03		+++	0 0 0 0
	7-10		++++	0 0 0 0	7 04		+++	63/0 2/0
	7-11		++++	57/69 2/4 11 D	7 05		+++	31/3 0 0
	7-12		+++	30/73 0/19	7 06		++	32/6 0 0
72	9-73		++	0 D	9-69		++	0 0 0
	9-74		+++	90 D	9 70		++	0 0 0
	8-55		++	0 0 0	8 20		+++	0 0 0 0
	8-58		++	3/0 0	8 28		++	0 0 0 0
	8-63		++	0 0 0	8 29		+	0 0 0 D
	8 53		+++	0 0 0	8 30		++++	99/12 3/11 D
	8-66		++	0 0 0	8-45		++	9/0 0
	8-71		++	3/0 0	8-48		+	0 0 0
	8-74		+++	0 0 0	8 59		+	0 60 0
	8-75		++	0 0 0	8 61		++	0 0 0
96	9-67		+	0 0 0				
	9-68		+	0 0 0				
	8-13		-	0 0 0	9 61		-	0 0 0
	8-60		-	0 0	9-66		-	0 0 0
	8-67		+	0 0	8 18		-	0 0 0 0
	8 69		-	0 0	8 22		+	0 0 0 0
	8-70		-	0 0	8 26		+++	0 0 0 0
	8-72		-	0 0	8 27		+	0 0 0 0
	8-76		-	0 0	8-39		+++	0 0 0 0
	8-77		++	0 0 0	8-40		-	0 0 0 0
	8 78		-	0 0	8-44		-	0 0
	8-81		+++	0 0	8-64		-	0 0
No. of days		1 2 3 4 5		1 2 3 4 5		1 2 3 4 5		1 2 3 4 5

TEXT-FIG 1 Characteristics of the disease produced by intradermal infection with *Pneumococcus* Type I in rabbits previously immunized with a heat-killed suspension of organisms of the homologous type. Immunization was carried out by a single intravenous injection of a suspension of heat-killed *Pneumococcus* Type I equivalent to 10 cc. of original culture. Intradermal infection was initiated by the injection of 0.2 cc. of a 1:5000 dilution of an 8 to 10 hours rabbit blood broth culture of virulent *Pneumococcus* Type I. Solid black shading indicates the number of days during which a rabbit's temperature was elevated to 104° or above. Absence of shading indicates absence of fever. Plus signs represent the occurrence of dermal lesions graded in severity from + to ++++ indicating one of maximal intensity. Minus sign indicates that no lesion developed. Cross hatching represents the incidence and duration of bacteremia. The small numbers in the cross hatched areas indicate the bacterial colony counts per cubic centimeter. Cultures of the blood which proved sterile are indicated by the symbol 0. D indicates animals which died, and with but one exception is placed so as to designate the day of death. Rabbit 7-11 died on the 11th day with persisting bacteremia.

The criteria for these comparisons include the incidence and duration of fever, the occurrence and severity of the lesions, the degree and duration of bacteremia, as well as the number of fatalities and the time of their occurrence. Temperatures of 104°F or above were considered abnormal. The degree of temperature elevation is not included in this report since in most instances high fever continued until the time of death or recovery. The severity of lesions has been designated by the symbols + to +++++, to represent the gradations of dermal involvement varying from a small circumscribed tuberculin like reaction to an extensive area of dependent inflammatory edema with ecchymosis and necrosis. The most severe reactions were usually observed in the unvaccinated control animals, but not invariably, since several died before the lesions appeared to be fully developed. Evidences of incipient healing of the dermal infection usually paralleled other indications of recovery. The rate of healing seemed to depend upon the extent and severity of the lesions. The outcome of the infection, however, could not be predicted from the severity of the local inflammatory process, for many of the animals infected 48 hours after vaccination had lesions of maximal intensity but ultimately survived.

In all of the control animals, and with but two exceptions among the 23 vaccinated rabbits which developed bacteremia, cultures of the blood taken 24 hours after infection yielded growth of *Pneumococcus* Type I. In most of the vaccinated rabbits, notably those with low initial colony counts, cultures of the blood became sterile coincidentally with other evidences of recovery, whereas in some of the vaccinated and in all of the unvaccinated rabbits, bacteremia persisted and progressively increased until the time of death. From seven of the eight fatalities among the 62 immunized rabbits, *Pneumococcus* Type I was isolated in cultures of the blood taken during life or at autopsy. The single exception was the rabbit mentioned above which may have died of sulfapyridine intoxication.

*Non-Immunized Rabbits*—In the 26 control animals which received no sulfapyridine the infection followed a uniformly fatal course. Included in this number are those rabbits which received 1/10 or 1/100 of the inoculum employed routinely in infecting the vaccinated animals. High fever persisted usually until the time of death and the lesions were characteristically of maximal intensity. Cultures of the blood taken 24 hours after infection yielded from three to myriad colonies per cubic centimeter, and in every instance overwhelming blood stream invasion occurred prior to the invariably fatal termination within 6 days. In the four unvaccinated rabbits which received sulfapyridine the course and termination of the disease were identical.

*Rabbits Infected 48 Hours after Immunization*—(Text fig 1) Ten rabbits which received preliminary administration of sulfapyridine and ten which did not were infected 48 hours after immunization. As shown in Text fig 1 all of the untreated rabbits and all but two of those treated with the drug developed

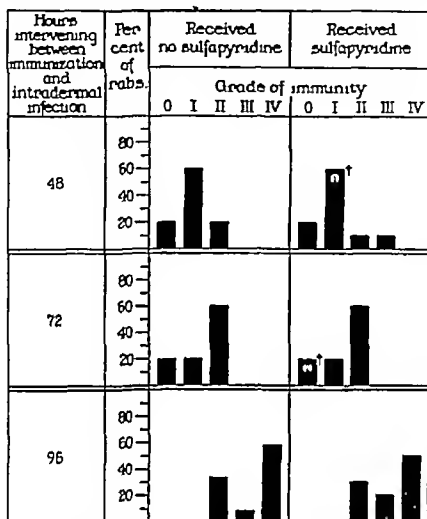
fever which lasted from 1 to 5 days, averaging about 3 days in the febrile animals of both groups. The lesions varied in severity from ++ to ++++ in both groups. On the whole the intensity of the lesions was perhaps a little less severe in the treated than in the untreated animals. However, eight of the rabbits in each group had positive blood cultures 24 hours after infection. Although the severity of illness in most of the rabbits was such that death seemed imminent over a period of several days, only two animals from each group ultimately succumbed, three within 4 days and one on the 11th day following persistent bacteremia.

*Rabbits Infected 72 Hours after Immunization*—(Text-fig 1) In the ten treated and ten untreated rabbits which were infected 72 hours after immunization the manifestations of infection were considerably less than in the comparable groups of animals infected 24 hours earlier. Although fever occurred in every instance it was of shorter duration, averaging about  $1\frac{1}{2}$  days in the untreated and  $2\frac{1}{2}$  days in the treated animals. The severity of the lesions was also less intense averaging about ++ in both groups with extreme variations of + to ++++. Bacteremia occurred in four of the untreated rabbits of which two died, and in three of the treated animals of which one died. One treated rabbit which did not have bacteremia died on the 4th day of illness.

*Rabbits Infected 96 Hours after Immunization*—(Text-fig 1) Half of the rabbits infected 96 hours after immunization, whether treated or untreated, seemed to be unaffected by the same inoculum of *Pneumococcus* Type I producing severe disease in animals infected after shorter intervals. Only four of twelve untreated and three of ten treated rabbits developed fever. The average duration was 2 days in each group. Lesions occurred in five animals of each group and were for the most part of minimal intensity with individual variations in severity to ++++. None of these animals developed bacteremia and all survived.

*Active Immune Response at Different Intervals Following Immunization*—In the immunized rabbits manifestations of the disease produced by intradermal infection were progressively less severe as the interval between immunization and infection was increased. The enhancement of resistance to infection in animals which had not received sulfapyridine could be explained only on the basis of an immune response to vaccination. Likewise, in the animals which received sulfapyridine there was no evidence to contradict this assumption. In order to compare the degree of active immunity in the respective treated and untreated groups of animals, and thereby determine whether or not the response in treated animals was affected by drug administration, a modification of the classification devised by Goodner (19) has been employed. Immunized rabbits which showed all the characteristics of the disease invariably noted in the controls, including a fatal termination, were considered to have no immunity. Those which showed no manifestations of disease were re-

garded as completely immune to the infecting dose employed. Grades of immunity between these extremes have been observed as indicated in Text fig 2. With only two exceptions each rabbit could be readily classified in one of



TEXT FIG 2 Active immunity in rabbits at different intervals following immunization.

Grade of immunity	Corresponding characteristics of disease
0 = no immunity	Fever, lesion, bacteremia, and death.
I =	Fever, lesion, bacteremia survived.
II =	Fever and lesion no bacteremia, survived.
III =	Minimal lesion, no fever no bacteremia survived.
IV = complete immunity	No evidence of disease, survived

All of the control animals had 0 immunity

† Only 2 animals did not fit readily into these categories (1) moderate lesion and bacteremia, no fever, survived, (2) fever and lesion, no bacteremia died.

the designated categories. Since all of the unvaccinated control animals showed no immunity they have not been included in the chart.

It is evident that as early as 48 hours after immunization most of the treated and untreated rabbits had some degree of resistance to intradermal infection. This is indicated chiefly by the fact that 80 per cent of the animals in both groups survived. The immunity was of a low order, however. 60 per cent

velopment of circulating antibodies as well as the early development of active resistance is not influenced by the administration of sulfapyridine

#### DISCUSSION

It is evident from the experimental data that the administration of sulfapyridine has no appreciable effect upon the immune response in rabbits following a single intravenous injection of heat-killed suspension of *Pneumococcus* Type I

Of particular significance is the fact that active immunity, as indicated by resistance to intradermal infection, was present 48 hours before any appreciable immune response could be detected by tests for circulating antibody 96 hours after vaccination, when antibodies were first demonstrable in the sera, all of the animals tested were almost solidly immune to intradermal infection

Of the techniques employed for the determination of circulating antibody, the mouse protection test was found to be the most sensitive, revealing the presence of antibody in approximately twice as many instances as did the test for agglutinins or precipitins

The precipitin reaction, although an exquisitely sensitive method for the detection of minute amounts of capsular polysaccharide, is less satisfactory than the mouse protection and agglutination tests for the purpose of demonstrating small amounts of antibody. As the precipitate which forms the basis of this reaction is composed almost entirely of antibody, small amounts of antibody may fail to produce a visible reaction with varying dilutions of antigen although in the presence of adequate antibody the reaction with antigen in dilution as high as 1:5,000,000 may yield a visible precipitate. Furthermore, when used to test the sera of patients with pneumococcal pneumonia the precipitin reaction introduces another possible factor of error. If the preparation of capsular polysaccharide employed is contaminated with even a trace of the pneumococcus C polysaccharide the reaction of the latter substance with the C reactive protein of acute phase serum may be misinterpreted as an indication of the presence of type specific antibody (20, 21)

In man studies comparable to those which can be carried out in experimental animals are not feasible. Because of the many variables existing in the patient with pneumococcal pneumonia it would be impossible to conclude from the failure to demonstrate circulating type specific antibody that resistance to infection had not developed or that administration of a sulfonamide drug had affected the development of immunity.

Either failure to produce sufficient circulating antibody or the removal of free antibody by combination with circulating antigen could preclude the detection of antibody. In any event, positive results indicate only that an excess of antibody is present, whereas negative results may signify merely that such an excess cannot be demonstrated by the techniques available.

Experimental observations, however, point clearly to the fact that a considerable type specific immune response to pneumococcus develops rapidly and may be adequate to protect against infection in the absence of demonstrable circulating antibody. Although the various types of pneumococci vary in their ability to stimulate antibody formation it seems unlikely that the sulfonamide drugs exert different effects upon this particular property in different types of pneumococcus. From the present study it appears that the development of immunity in response to a specific antigenic stimulus proceeds according to the effectiveness of the stimulus irrespective of whether sulfapyridine has been administered.

#### SUMMARY

1 Sulfapyridine, administered to rabbits during the period of developing immunity after a single intravenous injection of heat killed *Pneumococcus* Type I, exerted no influence upon the immune response

2 Active immunity as indicated by increased resistance to homologous intradermal infection was present 48 hours after the immunizing injection and 2 days before circulating type specific antibodies were detectable

3 Of the serological techniques employed for the detection of circulating antibody the mouse protective test yielded the highest percentage of positive results followed in order by tests for type specific agglutinins and precipitins, the latter being least satisfactory for the detection of small amounts of antibody

#### CONCLUSION

The experimental findings lend further support to the view that, in man, effective therapy of pneumococcal infections with sulfonamide drugs is intimately associated with the development of active immunity

#### BIBLIOGRAPHY

- 1 Long P H., Bliss, E A., and Feinstone, W H, *J Am. Med Assn*, 1939, **112**, 115
- 2 Buttle G A. H *Proc Roy Soc Med* 1937 **31**, 154
- 3 Whitby L. E. H. *Lancet* 1938, **1**, 1210
- 4 McIntosh J and Whitby, L. E H. *Lancet*, 1939, **1**, 431
- 5 Calleno C., *Biochim terap sper*, 1939 **28**, 338
- 6 MacLeod C., *J Am. Med Assn*, 1939, **113**, 1405
- 7 Larson W P Bieter, R. N., and Levine M *Proc. Soc. Exp Biol and Med*, 1939 **40**, 703
- 8 Levine M. Larson W P and Bieter, R., *Proc Soc. Exp Biol and Med* 1939, **42**, 515
- 9 Edwards J C, Kircher, T, and Thompson L D *Proc. Soc Exp Biol and Med* 1939 **42**, 539

- 10 Wood, W B , Jr , and Long, P H , *Ann Int Med* , 1939, 13, 612
- 11 Finland, M , Sprung, W C , Jr , and Lowell, F , *J Clin Inv* , 1940, 19, 179
- 12 Fox, W W , Rosi, R , and Winters, W L , *Am J Med Sc* , 1940, 200, 78
- 13 Fox, W W , Rosi, R , and Winters, W L , *Am J Med Sc* , 1940, 200, 649
- 14 Kneeland, Y , Jr , and Mullikin, B , *J Clin Inv* , 1940, 19, 307
- 15 Kneeland, Y , Jr , and Mullikin, B , *J Clin Inv* , 1940, 19, 735
- 16 Bukantz, S C , and de Gara, P F , *J Immunol* , 1940, 39, 195
- 17 Bratton, A C , and Marshall, E K., Jr , *J Biol Chem* , 1939, 128, 537
- 18 Goodner, K., *J Exp Med* , 1928, 48, 1
- 19 Goodner, K., *J Exp Med* , 1928, 48, 413
- 20 Tillett, W S , and Francis, T , Jr , *J Exp Med* , 1930, 52, 561
- 21 Abernethy, T J , and Francis, T , Jr , *J Exp Med* , 1937, 65, 59

## COMPARATIVE DIABETOGENIC ACTION OF THE HYPOPHYSIS FROM VARIOUS ANIMALS

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The rôle of the anterior portion of the hypophysis in the production or intensification of diabetes was discovered in this Institute in 1929 and 1930 and since then has been studied continuously. An abstract of this work up to 1935 was published by Houssay in 1936. Some of the extracts of anterior hypophysis in animals without hypophysis and pancreas and with mild diabetes, intensified the hyperglycemia and glycosuria to a degree exceeding the intensity of the diabetes associated with pancreatectomy alone. This was observed in the toad (Houssay and Biasotti, 1930), and in the dog (Houssay and Biasotti, 1932, Houssay, Biasotti, and Rietti, 1932, Houssay, Biasotti, Di Benedetti, and Rietti, 1932). These latter observations suggested a possible method of biological assay of the diabetogenic factor. The present experiments were undertaken to demonstrate the relative potency of the diabetogenic principle in extracts of the anterior hypophysis from various species.

### *Test Animals*

(a) *Dogs*—The hypophysectomized-pancreatectomized dog is difficult to maintain in good condition because the injection of anterior hypophyseal extract profoundly aggravates its condition. On the other hand insulin cannot be used since they are so sensitive to this agent they develop fatal hypoglycemia from doses as low as 1 to 3 units per day. Normal dogs, while not showing this marked insulin sensitivity require such large amounts of anterior hypophyseal extract (between 1 and 2 gm. per kilo per day for several days) as to prohibit its extensive use for titrating the diabetogenic principle. Mention should be made that this diabetes in normal dogs characterized by hyperglycemia, ketonemia, hyperlipemia, acidosis etc., (Houssay, 1936) is produced specifically by anterior hypophyseal extracts, extracts of other organs being inert. The hyperglycemia which is preceded and accompanied by increased insulin resistance appears between the 2nd and 5th days after starting with the injections. Upon discontinuing the injections, blood sugar returns to normal in 1 to 3 days. If the animal fasts, the injections produce insulin resistance without hyperglycemia.

Dogs with subtotal pancreatic resection demonstrate Sandmeyer's diabetes if less than 3 gm. of pancreas are left. This attenuated diabetes is not permanent since it



may either improve or advance progressively to a fatal termination. In many cases this diabetes disappears with hypophysectomy if the hyperglycemia and glycosuria are not intense and if the animal is not in a cachectic condition. The injection of anterior lobe extract in a dog having Sandmeyer's diabetes rapidly aggravates the diabetic symptoms and results in death (Houssay, Biasotti, and Rietti, 1932).

If 3 to 6 gm of pancreas are left in the dogs, they remain normoglycemic and in good condition, but none the less very sensitive to the diabetogenic action of the anterior hypophyseal lobe extract (Houssay, Biasotti, and Rietti, 1932). We have demonstrated that as the pancreatic tissue is reduced surgically, smaller doses of anterior hypophyseal lobe become necessary. The difficulty with the very large pancreatic resections is that the dog may remain permanently diabetic if large or repeated doses of anterior pituitary extract are given. In these partially pancreatectomized dogs (retaining 3 to 6 gm of pancreas) with normal glycemia, a permanent diabetes was first obtained with anterior lobe extract. This diabetic state persisted in spite of discontinuance of injections of anterior hypophyseal extract and ultimately resulted in cachexia and death (Houssay, Biasotti, and Rietti, 1932). This phenomenon has since been confirmed in the rat by Long (1937, 1939), and in the cat by Dohan and Lukens (1939), and Lukens and Dohan (1940). Young (1937) later made the important observation that when the normal dog was injected with progressively increased doses of anterior hypophyseal extract, diabetes was produced and persisted even though the hypophyseal extract injections were discontinued.

The dogs with subtotal pancreatic resection but with normal glycemia are very sensitive to anterior hypophyseal extracts but they present two difficulties: (1) permanent hypophyseal diabetes may be obtained in some cases (4 cases of the first 12 dogs studied), (2) very exceptionally hyperglycemia and glycosuria may be obtained from large doses of extracts of tissues other than hypophysis, once in the case of muscle and of thyroid gland in our large report of experiments. These two difficulties may be met by (1) leaving at least 4 gm of pancreas, (2) injecting the animals no longer than 4 days, and (3) allowing 7 to 10 days to elapse before beginning a new series of injections.

Dogs with extensive pancreatic resection when hypophysectomized, maintain a great sensitivity to the anterior hypophysis extract without showing non-specific diabetogenic reactions. When the anterior hypophysis treatment is suspended, the glycemia rapidly returns to the normal level and with few exceptions the dogs recover from diabetes, providing the rules mentioned in the preceding paragraph are followed. The animals do not require special care and maintain excellent general health and have been successfully used by Houssay and Biasotti (1938) in their investigations and in the present study.

In the normal dog the anterior hypophyseal lobe of the ox has a diabetogenic action. From 1932 to the present we have injected this substance into more than 500 animals. The bovine anterior lobe showed diabetogenic action in normal animals such as dogs, cats, pigeons, and guinea pigs (listed in order of decreasing action). The action is still less on rats, rabbits, and white mice. It has no action on either toads or serpents (Houssay, Biasotti, and Rietti, 1933). According to Young (1938) this action is constant in dogs but inconstant in cats and rabbits. Rats, mice, and guinea pigs fail to show a diabetogenic response.

(b) *Toads*—In terms of response to the diabetogenic action of hypophyseal extract, the toad deprived of hypophysis and pancreas is the most sensitive animal yet observed. However, the animal lives but a short time after removal of the pituitary and pancreas, and there are marked individual and daily variations in response to the injections of anterior hypophyseal extract. Comparative experiments must be done in many animals on the same day and under identical conditions with adequate controls. Groups of 15 to 20 toads were used in each series.

The diabetogenic action of the hypophysis of different species of animals has been studied in the toad and in other batrachians deprived of the hypophysis and pancreas. In the toad *Bufo arenarum* Hensel the hypophysis of the same toad is diabetogenic (Houssay and Biasotti, 1930) as well as that of fish, chicken, ox, dog and man (Houssay and Biasotti, 1931) and also that of *Xenopus laevis*, *Leptodactylus ocellatus*, and *Bufo paracnemis*. Conversely in *Bufo paracnemis* there was a response from *Bufo arenarum* Hensel. In the frog, *Leptodactylus ocellatus* (L.) Gir, *Ceratoophrys ornata*, and *Bufo d'Orbigny* without hypophysis and pancreas, the hypophysis of the same animal has diabetogenic action. In the toad, extracts of other organs of toads and of other species (amphibian, bovine or human) are not diabetogenic.

The neurointermediate lobe of the hypophysis of the toad (equivalent histologically and physiologically to mammalian posterior lobe) has a diabetogenic action, although it is less than that of the pars distalis (equivalent histologically and physiologically to mammalian anterior lobe). Likewise the bovine posterior lobe of the hypophysis has some action but it is less active and more toxic than that of the anterior lobe of the same species (Houssay and Biasotti, 1930).

#### EXPERIMENTAL DATA

The diabetogenic action of the hypophysis from various animals (fish, batrachian, birds, mammals) was studied in normal dogs, in hypophysectomized dogs with 4 gm of pancreas and in toads deprived of their hypophysis and pancreas. The diabetogenic action of the serpent hypophysis was not studied in the dog because it had given poor results in the toad, and because it was not possible to obtain sufficient amounts for use in mammals.

#### Experiments on Dogs

*Methods*—In a few instances normal dogs were injected with human hypophysis in order to verify its diabetogenic action in the animal not deprived of any organ. In the remainder of the experiments 9 hypophysectomized male dogs, with pancreas reduced to about 4 gm, were used to test the diabetogenic principle.

Under ether anesthesia with midline incision partial pancreatectomy leaving the adherent portion to the duodenum with the main excretory duct was first performed. Several days later, when the dog had recovered from the operation, total hypophysectomy was done under ether anesthesia using the temporal route. The animals were not injected with hypophyseal substance until they had completely recovered from the surgical procedures and only when they were in excellent general health, usually several months after hypophysectomy. Two dogs were used after almost 4 years (Table I).

The dogs were mostly males with an average weight of 10 kilos (from 7.5 to 11.8 kilos) and were kept in metabolism cages and fed raw beef (35 to 40 gm per kilo per day). Fasting blood specimens were taken in the morning preceding the day on which the course of injections was started and on the 4 subsequent days before the injections were given,  $\pm$  c, 18 hours after meals and 16 hours after the preceding injection. A small cut on the margin of the ear gave the necessary amount (0.2 cc.)

TABLE I  
*Date of Operations and Sensitivity of Dogs Used*

Dog No		Terminal state	Weight	Amount of bovine anterior hypophysis exerting diabetogenic action per day	
				Fresh	Dry
			kg	mg per kg	mg per kg
5-77	Pancreatctomized 8-4-1937 Hypophysectomized 9-25-1937	Died of diabetes 9-6-1940	10.5	40	9.4
5-78	Pancreatctomized 8-18-1937 Hypophysectomized 9-25-1937	Died of distemper 6-4-1938	9	20	4.7
5-88	Pancreatctomized 11-20-1937 Hypophysectomized 12-15-1937	Died of diabetes 4-2-1938	9.5	40	9.4
5-93	Pancreatctomized 12-31-1937 Hypophysectomized 3-12-1938	Died of distemper 12-4-1939	10	20	4.7
6-03	Pancreatctomized 10-20-1938 Hypophysectomized 11-15-1938	Died of diabetes 12-29-1939	11.8	40	9.4
6-07	Pancreatctomized 10-14-1938 Hypophysectomized 11-21-1938	Alive 6-15-1941	10.1	40*	9.4
6-10	Pancreatctomized 12-16-1938 Hypophysectomized 3-3-1939	Alive 6-15-1941	8.6	20	4.7
6-26	Pancreatctomized 9-27-1939 Hypophysectomized 10-21-1939	Sacrificed 10-16-1940	9.1	40†	9.4
6-27	Pancreatctomized 9-27-1939 Hypophysectomized 10-21-1939	Sacrificed 10-21-1940	7.5	20†	4.7

\* Later there was not diabetes with 500 mg per kilo per day

† Later there was not diabetes with 150 mg per kilo per day

for the Hagedorn-Jensen procedure with deproteinization by the Somogyi technique, for determination of the blood sugar

Hypophyses of various species of animals were used (human, bovine, sheep, dog, rat, guinea pig, chicken, serpent, toad, and fish). The human hypophysis was obtained from the Pathology Department.<sup>1</sup> The other hypophyses were taken from

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adult normal animals of both sexes. The glands were removed immediately after the death of the animals, except for those of human and fish origin, which were removed a longer period after death and those from chickens which were removed a few hours postmortem. Hypophyses of the rats and guinea pigs were utilized fresh. Some were dried on a watch crystal (toad) and others such as those of human beings and dogs were placed in acetone, pulverized after 2 days and then kept in sulfuric acid vacuum. The hypophyses of hens and fish were used as whole glands but those from the other species of animals were used as separate lobes as is noted in each particular case. The glands were triturated in a mortar, suspended in physiological saline solution, and finally stored in the refrigerator until used.

TABLE II

Species	Number of glands used	Anterior lobe			Posterior lobe	
		Fresh	Dried	Acetone powdered	Fresh	Dried
		mg	mg	mg	mg	mg
Human beings	10	346	83	66	71	15.3
Dogs	40	43	10	7.09	12.8	3
Bovine	1836	2000	470	435	400	86
Guinea pigs	3	15.33	2.83	2.60	4.33	0.97
Rats	30	4.57	1.097	0.83	1.43	0.343
Toads	100	3.3	0.35	—	2.1	0.37
		Whole hypophysis				
"Merlusa"	6	8.3	1.3			
"Corvina"	6	5.9	0.9			
Chickens	7	6.3	1.3	1.04		

Toad (*Bufo arenarum* Hensel)

The fish 'merlusa' (*Merluccius hubbsi* Marini, 1939)

The fish 'corvina' (*Microgogon opercularis* Quoy and Gaimard 1824)

The weight of the whole gland or the weight of its lobes, was determined for the various types used in fresh or dried state and placed in sulfuric acid vacuum for preservation (Table II).

The bovine anterior hypophysis extract was prepared once a week. The gland was removed immediately after the animal was slaughtered and was placed at once in carbon dioxide snow. In the laboratory they were kept at a low temperature and the anterior lobe was separated and reduced to pulp with a meat grinder. Water (2 400 cc.) and 0.8 per cent sodium hydroxide (600 cc., previously cooled) were added to 800 gm. of prepared gland. The flask was shaken continuously while submerged in ice water and then placed in the refrigerator until the next day. The mixture was then acidified with 150 cc. of acetic acid (2.5 per cent), then alkalinized with NaOH (0.8 per cent) until a light alkaline reaction to phenol red indicator was observed. After centrifuging the mixture a clear supernatant portion was drawn off and stored in the frozen state in 60 cc. containers.

All injections were given by the peritoneal route twice a day for 4 consecutive days using physiological saline solutions (0.8 per cent) as a vehicle for the hypophyseal substance. The volume used varied in relation to the dose of hypophysis admin-

istered but always was less than 5 cc. All possible precautions for asepsis were taken and we have not observed any kind of infection although the sterilization of the extract could not be perfect because of the nature of the material injected

On each test dog the diabetogenic action of the bovine anterior hypophyseal lobe extract was determined by injecting the same dose daily for 4 consecutive days. If the fasting blood sugar determination reached 150 mg per cent or more it was considered as a positive result. When the test was completed the animal was kept at rest (in normoglycemia) from 7 to 10 days before being used for further determinations. If the initial dose was inactive, larger doses were given 4 to 7 days later until a positive result was obtained.

After a rest interval the diabetogenic action of the hypophysis of another animal species was determined in the same manner.

*Results—Bovine Hypophysis* The dog's sensitivity to bovine anterior hypophysis was fairly constant (see Table III). A positive result was obtained with 20 mg per kilo per day in 3 dogs and with 40 mg per kilo per day in the other 6 animals. From time to time this potency was verified by test. It did not change in 3, it increased in 3, the dogs remaining permanently diabetic and in the other 3 a definite decrease of such sensitiveness was observed. Not all the anterior hypophyseal extracts have the same activity. Nevertheless, it is possible to notice that the dog's sensitivity itself changed little during the long experimental periods (Table III).

The bovine anterior hypophysis produced a diabetogenic action on the dog with its pancreas intact. A positive result was observed with 500 mg per kilo per day for 4 consecutive days in 14 per cent of the animals, with 1,000 mg per kilo per day in 53 per cent, and with 1,500 mg per kilo per day in 70 per cent. On the hypophysectomized and partially pancreatectomized dogs (with 4 gm of pancreatic tissue) doses of 20 mg of extract per kilo per day in 3 dogs and 40 mg per kilo per day in 6 dogs were sufficient to obtain diabetogenic action. In other words, they were 25 to 40 times more sensitive than normal dogs.

*Human Hypophysis* The diabetogenic action of human hypophysis was verified in normal as well as in hypophysectomized and pancreatectomized dogs (with 4 gm of pancreatic tissue left). From autopsy material 170 human hypophyses were assembled, the lobes separated, stored in acetone, and dried. An alkaline extract was prepared from this material in powder form by the described technique and placed in the refrigerator.

Three normal dogs were injected intraperitoneally. In the first, the extract from 59 anterior hypophyseal lobes was given in 4 days, the remaining 2 received the extract from 55 lobes in 2 days. The diabetogenic action was definite in the second dog and incomplete in the first and third dogs (Table IV).

In the dogs deprived of their hypophyses and of a part of their pancreas the diabetogenic action was obtained with 13 mg (or a little over that amount) per kilo per day of fresh anterior lobe extract (Table IV). This finding demon-

strates that human hypophysis has a marked diabetogenic action notwithstanding the fact that two unfavorable factors diminished the activity (1) the

TABLE III

*Dogs Deprived of Hypophyses and with Only 4 Gm of Pancreatic Tissue Injected Peritoneally  
[Twice a Day for 4 Days with Alkaline Extract of Fresh Anterior Lobe of Bovine  
Hypophysis (33 Per Cent in Physiological Solution) Blood Sugar Determined from Capillary Blood from Ear Margin, Animals Being  
without Food for Previous 12 Hours]*

Date	Dog No.	Weight	Injected hypophysis per kg per day		Blood sugar				
			Weight		Days				
			Fresh	Dry	0	1	2	3	4
		kg	mg	mg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
11 23-37	5-77	10.2	20	4.70	26	—	88	127	106
12 26-39	5-77	10.5	20	4.70	67	108	84	62	74
6-27-40	5-77	10.5	20	4.70	93	139	133	196	107
3-10-38	5-77	10	40	9.41	92	—	204	—	255
12 11-39	5-77	10.5	40	9.41	97	147	201	300	—
7-1-40	5-77	10.5	40	9.41	78	116	177	206	121
11 15-37	5-77	10.5	100	23.52	102	131	—	290	—
10-19-37	5-77	10.6	400	94.08	98	276	—	—	—
	5-78	9	20	4.70	96	—	—	135	—
	5-78		40	9.41	94	—	210	—	225
	5-78		100	23.52	98	106	—	235	—
	5-78		400	94.08	91	—	—	—	280
3-10-39	5-88	9.5	40	9.41	98	—	236	—	272
3-21-38	5-93	10	20	4.70	119	—	—	—	177
3-10-35	5-93	10	100	23.52	102	131	—	290	—
2 3-39	5-93	10	100	23.52	104	105	115	195	230
12 11-39	6-03	11.8	40	9.41	147	207	259	335	—
9-18-39	6-03	11.8	200	47.04	90	—	85	99	—
12-26-39	6-07	10.1	20	4.70	103	101	95	80	119
12-11-39	6-07	10.1	40	9.41	111	138	160	240	—
12 26-39	6-10	8.6	20	4.70	76	172	259	211	247
12-11-39	6-10	8.6	40	9.41	104	238	221	236	—
6-27-40	6-10	8.2	20	4.7	84	122	253	265	—
12-26-39	6-26	9.1	20	4.7	69	106	—	77	92
12 11-39	6-26	9.1	40	9.41	100	93	195	209	—
7 22-40	6-26	11.0	80	18.80	86	91	94	99	89
8-2-40	6-26	11.0	150	35.23	81	102	104	108	129
12-26-39	6-27	7.5	20	4.7	92	106	—	209	191
12-11-39	6-27	7.5	40	9.41	113	129	138	161	—
7-22-40	6-27	8	40	9.40	79	94	90	89	101
7 29-40	6-27	8.5	80	18.40	88	95	96	104	107
8-5-40	6-27	8.5	150	35.2	93	103	108	113	138

glands were obtained postmortem from individuals who had been ill, and (2) 6 to 24 hours had elapsed before the gland was available for extract.

*Rat Hypophysis* The anterior hypophysis of the white rat produced diabetogenic action in doses of 100 glands in 4 days, i.e., 25 glands a day (11.43 mg of fresh glands per kilo per day) on a dog previously responding to 20 mg bovine gland per kilo per day (Table V) There was no action with 40 nor with 20

glands of anterior hypophysis of the rat injected in 4 days The posterior lobe had no action in doses of 40 lobes in 4 days

*Dog Hypophysis* The hypophysis of the dog showed little diabetogenic activity in our few experiments Diabetogenic action was obtained with 100 glands, but 50 glands injected in 4 days failed to produce any action in 1 dog which had responded to 80 mg per kilo per day of bovine anterior hypophyseal lobe extract (Table V) Because of the few animals used, and also because of

TABLE IV  
*Normal and Test Dogs Injected with Human Hypophysis*

Date	Dog No	Weight	Injected hypophysis per kg per day					12 hr fasting blood sugar				
			No. of lobes injected		Weight			Days				
			Ante rior lobe	Poste rior lobe	Fresh	Dry	Acetone dried and pow dered	0	1	2	3	4
1940		kg			mg	mg	mg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
Normal dogs												
6-29	—	6 0	2 36	—	850	200	160	100	98	119	121	110
11-25	—	7 5	3 66	—	1260	300	230	90	112	173	—	—
11-28	—	6 7	4 10	—	1410	340	260	80	79	110	—	—
Dogs with reduced pancreas (4 gm) and without hypophysis												
5-17	6-27	7 5	0 025		8 70	2 09	1 66	84	89	114	87	82
4-15	6-07	10 1	0 026		9 17	2 20	1 75	71	73	102	98	93
5-6	6-07	10 1	0 031		10 48	2 52	2 00	92	97	82	102	81
4-1	5 77	10 5	0 037		13 04	3 13	2 38	80	112	167	235	212
5-6	5-77	10 5	0 037		13 04	3 13	2 38	97	111	177	200	139
4-15	6-10	8 6	0 044		15 25	3 66	2 91	89	170	286	280	239
4-15	6-27	7 5	0 046		15 72	3 77	3 00	74	91	94	100	128
3-11	6-07	10 1	0 075		26 20	6 29	5 00	80	83	147	318	298
3-17	6-26	9 1		0 044	3 15	0 68		76	89	76	69	69
4-1	6-26	9 1		0 18	12 71	2 74		71	80	83	74	82
3-11	6-10	8 6		5	7 74	1 66		81	95	104	213	265
5-13	6-10	8 6		8	13 50	2 91		92	81	89	98	88

the increasing resistance of the test animal, a final conclusion regarding the minimal active dose cannot be reached On the other hand, in toads without hypophysis and pancreas, the diabetogenic action of the dog hypophysis is extremely intense There was no action with 93 posterior hypophyseal lobes of the dog injected in 4 days

*Sheep Hypophysis* We have verified the action of the sheep anterior hypophyseal lobe in normal dogs (1,500 mg per kilo per day), but we have not titred it in our partially pancreatectomized animals

*Guinea Pig Hypophysis* Fresh anterior lobes of 36 guinea pigs (13 3 mg per kilo per day) had no diabetogenic action nor did posterior hypophyseal lobes of 36 guinea pigs (6 0 mg per kilo per day) in dogs sensitive to 150 mg per

kilo per day of bovine hypophysis extract. Larger doses might have been active but were not used

*Chicken Hypophysis* Diabetogenic action was obtained with 237 whole hypophyses of chickens (35 mg per kilo per day) injected in 4 days. There was a rise of blood sugar to 144 mg per cent with 180 hypophyses of chickens

TABLE V

*Dogs without Hypophysis and with About 4 Gm of Pancreas, Injected Intraperitoneally Twice Daily for 4 Days with Hypophysis of Various Animals*

Date	Dog No	Weight	Hypophysis injected per kg per day					Blood sugar				
			No of lobes		Weight			Days				
			Anterior lobe	Posterior lobe	Fresh	Dry	Acetone and powdered	0	1	2	3	4
		kg			mg	mg	mg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
<i>Toad Bufo arenarum Hensel (dried pars distalis)</i>												
10-9-39	6-10	8.6	1.45	—	4.8	0.8	—	71	102	106	105	115
9-5-39	6-07	10.1	2.50	—	8.2	1.4	—	90	107	96	129	131
9-27-39	6-10	8.6	2.90	—	9.6	1.6	—	112	153	122	146	233
9-22-39	6-10	8.6	3.31	—	19.2	3.2	—	70	103	182	328	297
<i>Chicken (fresh whole hypophysis)</i>												
2-27-40	5-77	10.5	0.48	—	3.00	0.62	0.495	83	91	96	93	85
3-11-40	5-77	10.5	2.38	—	15.00	3.09	2.47	82	79	92	108	144
4-15-40	5-77	10.5	3.64	—	33.55	7.33	5.87	91	86	133	142	150
<i>Rat (fresh anterior lobe)</i>												
10-5-38	5-93	10.0	0.50	—	2.28	0.55	—	98	—	102	95	—
12-11-40	6-26	9.1	1.11	—	3.03	1.22	—	86	79	93	82	101
9-5-38	5-93	10.0	2.50	—	11.43	2.74	—	98	—	—	208	243
3-11-40	6-27	7.5	—	1.33	1.91	0.46	—	76	78	81	74	90
<i>Dog (acetone dried and powdered)</i>												
4-1-40	6-07	10.1	0.40	—	17.02	3.96	4.32	87	80	101	113	82
5-13-40	6-27	7.5	0.90	—	38.70	9.00	8.00	81	92	109	98	93
7-16-40	6-10	8.0	1.59	—	67.0	15.15	10.9	88	97	95	95	106
9-30-40	6-07	9.0	3.77	—	119.0	27.7	15.6	65	82	112	243	286
4-1-40	6-10	8.6	—	0.43	5.58	1.31	1.16	91	89	85	88	81
5-13-40	6-26	9.1	—	0.72	9.24	2.17	2.77	78	83	91	96	81
10-14-40	6-07	9.0	—	2.50	33.0	7.7	5.22	73	84	97	95	97

(15 mg per kilo per day) injected in 4 days in a dog sensitive to 40 mg of bovine anterior hypophysis (Table V) The equivalent diabetogenic potency of chicken hypophysis compared to 20 mg bovine anterior hypophysis was between 7.5 and 15 mg

*Toad Hypophysis (Bufo arenarum Hensel)* The diabetogenic action of the pars distalis of the toad hypophysis (equivalent to the mammalian anterior lobe) has been studied by Foglia (1940) An intense diabetogenic action was obtained with 200 lobes in 1 animal and with 100 lobes in another injected in 4 days. In 1 dog sensitive to 20 mg per kilo per day of bovine anterior hypoph



However, we hesitate to make this conclusion final since (a) the number of experiments was small, (b) the test animals showed a rapid loss of sensitivity at the time of the test, and (c) the anterior hypophysis of the dog has been found to be very active diabetogenically when tested on the toad

We did not obtain a positive result with either anterior hypophysis of guinea pig or with the whole hypophysis of fish, probably because we did not use sufficient doses. The anterior hypophysis of the guinea pig is definitely active on toads and the hypophysis of the fish has a definite action on the same animal although it is inferior compared with that of the other animals studied

The anterior hypophysis of man has been shown to be the most active in partially pancreatectomized dogs as well as in hypophysectomized and pancreatectomized toads. But we obtained in addition a positive diabetogenic action in normal dogs with pancreas intact, with a daily dose of 1260 mg per kilo per day of fresh human anterior hypophysis lobe extract, in 2 days time

The diabetogenic power of the anterior hypophyses which were studied can be placed in the following order of decreasing activity, tested on toads deprived of their hypophysis and pancreas: human, dog, toad (*Bufo arenarius* Hensel), white rat, guinea pig, chicken (whole hypophysis), ox, snakes, "corvina" (*Micropogon opercularis*). We found in the dog a similar order (human, toad, rat, chicken, and ox). The activity of the dog hypophysis on the dog was not established with precision and insufficient amounts of the hypophysis of the guinea pig and "corvina" were injected to demonstrate their action

The diabetogenic action of the posterior lobe was also tested but smaller doses than that of the anterior lobe were injected. Nevertheless, it was verified by Houssay and Biasotti (1930 and 1931) on the toad and by Houssay, Biasotti, and Rietti (1932, 1933) on mammals that with equal weights its action is much less intense than that of the anterior lobe. Thus 12.7 and 13.5 mg per kilo per day of human posterior hypophysis and 33 mg per kilo per day of posterior hypophyseal lobe of the dog did not produce any diabetogenic action. In one instance, the diabetogenic action was obtained with 7.7 mg per kilo per day of human hypophysis in dog No. 6-10, but this result was due probably to an abnormal sensitivity of the dog on that date because it was not observed 2 months later in the same dog when 13.5 mg per kilo per day were given

The diabetogenic action of the anterior hypophysis must be considered as specific and peculiar to this organ, as has been demonstrated by Houssay, Biasotti, and Rietti (1932, 1933) because the extracts of other organs did not have such action in 4 days on the same dogs nor 660 mg per kilo per day of the liver or kidney of the toad (including the adrenals), nor 400 to 1000 mg per kilo per day of kidney, liver, spleen, testicle, muscle, and thyroid of dogs or oxen

Neither 30, 40, or 60 mg of corticosterone nor 80 to 200 mg of desoxy corti-

costerone, injected in 2 days produced the diabetogenic effect. Houssay and Biasotti (1938) did not obtain any action with prolactin (100 mg in 4 days) or with adrenotropic (adreno-cortico-tropic) extract sent by Collip (250 units), follicle stimulating hormone (F S H) (150 mg), and luteinizing hormone (L H) (100 mg, i.e., 100 units).

#### CONCLUSIONS

Of all the anterior hypophyses tested, those of the human produced the most marked diabetogenic action in the dog with its pancreatic tissue reduced to 4 gm., and in the hypophysectomized and pancreatectomized toad. The human hypophysis also produced diabetogenic action in the normal dog on daily doses of 1.26 mg per kilo per day for 2 days.

The hypophysectomized dog with its pancreas reduced to 4 gm. is very sensitive to the anterior hypophyseal diabetogenic action and is the best test animal for demonstrating such action in mammals.

The anterior hypophysis of man, toad, rat, and chicken produces in such animals a diabetogenic action with doses of from 10 to 15 mg per kilo per day. The bovine anterior hypophysis has identical action in 20 mg doses. That of canine origin was much less active in a few though inconclusive experiments.

It was impossible to demonstrate a diabetogenic action with either guinea pig hypophysis or with that of fish probably because insufficient doses were injected.

The diabetogenic action was not obtained by the injection of other organ extracts of toads, dogs and oxen, of corticosterone (30, 40, and 60 mg in 4 days) or of desoxycorticosterone (80 mg and 200 mg in 4 days).

The toad (*Bufo arenarum* Hensel), deprived of its hypophysis and pancreas is the most sensitive biological reactor for testing the diabetogenic action. In this animal the diabetogenic action of anterior hypophyses from varied sources decreased in the following order: man, dog, toad (*Bufo arenarum* Hensel), white rat, guinea pig, chicken (whole hypophysis), ox, serpent (*Constrictor constrictor* (L)), the fish "corvina" *Micropogon opercularis* (Quoy and Gaimard, 1824), and "merluza" *Merluccius hubbsi* (Marini, 1933).

#### BIBLIOGRAPHY

1. Dohan F C., and Lukens, F D W, *Am J Physiol*, 1939, 126, 478.
2. Foglia, V C. *Rev Soc. argent biol* 1940, 16, 340
3. Houssay B A. *New England J Med* 1936 214, 961
4. Houssay B A. and Biasotti, A. *Rev Soc. argent biol* 1930 6, 8 *Compt rend Soc. biol* 1930 104, 407 *Arch. ges. Physiol.*, 1931, 227, 239
5. Houssay B A. and Biasotti A. *Rev Soc. argent biol* 1930, 6, 251, *Compt rend Soc. biol* 1930 106, 121 124 *Arch. ges. Physiol*, 1931, 227, 664
6. Houssay B A and Biasotti, A., *Rev Soc. argent biol* 1930, 6, 326, *Compt rend Soc. biol.*, 1930, 106, 126 *Arch. ges. Physiol*, 1931, 227, 657

any attempt to deduce the natural history of the infection from a given pattern of virus distribution

In 1910, Flexner and Lewis (5) reported that Berkefeld filtrates of the mucous membrane of the nasopharynx obtained from recently paralyzed monkeys produced paralysis in other monkeys. In 1911, Landsteiner, Levaditi, and Danulesco (6) reported that a number of attempts to find virus in the nasal secretions of paralyzed monkeys failed until they inserted cotton plugs for 24 hours into the nostrils of 2 paralyzed *cynomolgus* monkeys, and inoculated the pooled filtrate intracerebrally and intraperitoneally into another monkey which developed typical poliomyelitis in 10 days. In three tests on the tonsils and peritonsillar mucosa obtained from three paralyzed *cynomolgi*, which were infected by the intracerebral route, one yielded the virus. In 1912, Levaditi and Danulesco (7) continued these studies and recorded the following observations: (1) tests with filtrates of the nasal mucosa obtained from 4 intracerebrally inoculated, paralyzed *cynomolgus* monkeys were all negative and they stated that similar tests on a larger number of monkeys were also negative, (2) filtrates of the nasal secretions obtained on tampons from 5 intracerebrally inoculated, paralyzed monkeys (2 *rhesus* and 3 *cynomolgus*) yielded negative results when the secretions from each paralyzed monkey were subinoculated separately into a new monkey, (3) when the nasal secretions from two other *cynomolgus* monkeys were pooled and subinoculated into a single monkey, virus was demonstrated, (4) six experiments in which tampons from infected monkeys were placed in the noses of normal monkeys were negative, (5) tests on the tonsils from 4 intracerebrally inoculated, paralyzed monkeys (1 *rhesus* and 3 *cynomolgus*) yielded one positive result with the material from one of the *cynomolgus* monkeys.

In more recent years a number of attempts to demonstrate the virus in the nasal or nasopharyngeal mucosa and secretions of paralyzed *rhesus* monkeys have yielded negative results. In 1938, Sabin and Oltsky (8) observed that even after nasal instillation of highly potent "M V" virus in *rhesus* monkeys none was found in the nasal mucosa and secretions at the time of paralysis, although virus was demonstrable at 72 hours after instillation by the method used. In the same year Sabin (2) reported that no virus was found in the nasal mucosa of 4 *rhesus* monkeys which succumbed with typical poliomyelitis after injection of "M V" virus by the tonsillo-pharyngeal route. In 1939, Kramer, Hoskwith, and Grossman (9) reported negative results when they subinoculated the nasopharyngeal and oral washings together with nasal and pharyngeal tissue obtained from 7 paralyzed *rhesus* monkeys some of which had been inoculated intracerebrally with "M V" virus and others intranasally with the "Armstrong" virus.

The early experiments probably differed from those carried out later on in that strains of virus of more recent human origin or *cynomolgus* monkeys were used, and in so far as larger amounts of virus might have been injected intracerebrally and intraperitoneally. Theoretically, it is possible that after injection of large amounts of virus intracerebrally some may escape along the known existing connections between the subarachnoid space and the interstitial tissues of the nasal mucosa, although Yoffey and Drinker (10) reported that "M V" virus inoculated intracerebrally or intranasally in *rhesus* monkeys could not be demonstrated in the lymph from the nasopharynx.

In so far as one is searching for corollaries to help explain events in the human disease, it is more relevant to know what happens when the virus has reached the central nervous system from a peripheral site than after intracerebral injection. Fully realizing that ultimately one will have to consider separately the behavior of different strains of virus in different hosts, it was decided to begin the experimental inquiry into the centrifugal spread of poliomyelitis virus with the monkey adapted "M V" strain in *rhesus* monkeys. The intrasciatic route of inoculation was selected chiefly because we had reason to expect that poliomyelitis could be produced regularly in this manner, and despite the fact that, according to a report by Hurst (11), virus can sometimes be found in the spinal fluid of such monkeys when the disease is fully developed although not in the earlier stages. Since poliomyelitis virus has never been demonstrated in the cerebrospinal fluid of human cases and rarely, if ever, in monkeys inoculated by other peripheral routes, the intrasciatic route of infection might thus perhaps be expected to favor the possibility of escape of virus from the subarachnoid space into the nose.

### General Plan

The plan of investigation was as follows: (1) inoculate "M V" virus into the sciatic nerve of a group of *rhesus* monkeys; (2) collect the nasal secretions on absorbent cotton plugs (the method by which successful isolation of virus from intracerebrally inoculated *cynomolgus* monkeys was reported by Landsteiner, Levaditi, and Danulesco (6) and by Levaditi and Danulesco (7)) every 24 hours during life; (3) pool the secretions collected during each 24 or 48 hours from several monkeys and test for virus; (4) when the monkeys were either prostrate or dead as a result of poliomyelitis infection a number of tissues selected for their capacity to indicate the extent of centrifugal spread of virus are to be obtained with special precautions to avoid contamination and tested for virus by subinoculation into new *rhesus* monkeys. The spinal cord was included in the group of tissues from each monkey to serve as a positive virus control. The tests on the olfactory bulbs were expected to indicate not only whether the virus had spread that far but also, in case virus were found in the nasal secretions or mucosa, whether the virus had reached the nose by a neuronal pathway or otherwise. The presence or absence of virus in the tonsils and pharyngeal tissue might be an index either of lymphatic absorption from the nose or centrifugal spread from the medulla. Tests on the superior cervical sympathetic ganglia, the abdominal sympathetic ganglia of the celiac plexus, the adrenals, small intestine, and salivary glands were expected to show how far virus localized in the central nervous system wandered into peripheral sympathetic ganglia or tissues containing collections of nerve cells of the parasympathetic system. It is well known that by the time a monkey is prostrate as a result of poliomyelitis infection specific neuronal lesions may be found in almost all the spinal ganglia and also in the sensory cranial ganglia regardless of the route of inoculation (Pette, Demme, and Környey (12), Bodian and Howe (3), and personal observations). It is apparent, therefore, that the virus spreads to the sensory neurons close to the spinal cord and medulla and

might thus perhaps be expected to involve also some of the nerve cells in the ganglia of the sympathetic trunk along the vertebral column in the thorax and abdomen although Pette, Demme, and Környey (12) stated that in general no neuronal lesions were found in these ganglia. Whether or not it can spread as far as the collateral ganglia, such as the celiac, or the terminal ganglia located within the viscera or glands that they innervate, is a question of considerable importance in any attempt to interpret a given pattern of virus distribution in cases where the original portal of entry of the virus is unknown.

### *Methods*

*Virus and Mode of Inoculation*—The "M V" strain of poliomyelitis virus was used. Before each experiment glycerinated cord was passaged and fresh virus was used for intrasciatic injection. With the monkey under ether anesthesia an incision through skin and muscle was made midway over the posterior aspect of the thigh and the sciatic nerve was then exposed by blunt dissection. 1 cc. of a 10 per cent lightly centrifuged suspension of the virus was then injected into the nerve using a 20 or 22 gauge needle which was moved back and forth within the sheath of the nerve for the purpose of cutting a certain number of nerve fibers and exposing their axis cylinders. While ballooning of the nerve occurred during the injection, most of the inoculum escaped into the surrounding tissues. It is noteworthy that of 8 monkeys so inoculated all developed poliomyelitis. In view of the fact that some investigators (Harrison and Woolpert (13), Toomey (14)) reported that in their experience most monkeys failed to develop poliomyelitis after intrasciatic injection and in view of the fact that it has been suggested that vitamin D deficiency may facilitate progression of poliomyelitis virus along peripheral nerves, it should be pointed out that 6 of the 8 monkeys in the present experiments either had no vitamin D deficiency to begin with or else had been given vitamin D (drisdol) for a period of 2 weeks prior to inoculation, in the other two monkeys both chemical and roentgen evidence of D deficiency were present. The relationship between vitamin D nutrition (as determined by the concentration of phosphorus in the blood and roentgen examination of the bones) and the invasiveness of poliomyelitis virus along peripheral nerves was studied on these monkeys but the data will be presented in another communication (15).

*Collection and Preparation of Nasal Secretions for Subinoculation*—Directly the intrasciatic inoculations were completed, absorbent cotton was plugged into each nasal cavity. At the end of 24 hours these plugs were removed and new ones were inserted. The moist plugs were kept in a refrigerator or frozen by means of solid CO<sub>2</sub>. This process was repeated every 24 hours until the monkey was dead or sacrificed. In the first series of tests the cotton plugs for each 24 hours from each of 4 monkeys were pooled for subinoculation into a new monkey. In the second series of tests the cotton plugs for each 48 hours from each of 2 monkeys were pooled. As much as possible of the original nasal juice was expressed from the cotton plugs and further extracts were obtained by maceration with physiological salt solution following the same procedure of extraction, centrifugation, and etherization that was used in similar tests on human beings and described in a previous communication (16). The untreated (unetherized) centrifuged sediments were instilled intranasally into the same monkeys which received the etherized supernatant liquids intracerebrally and

intrapentoneally. Some of the etherized material was saved for a second intracerebral inoculation 4 to 7 days later. Several monkeys died of a bacterial pneumonia until the ether anesthesia used for the intracerebral inoculation was replaced by local anesthesia.

*Collection and Preparation of Tissues for Subinoculation.*—The various tissues were obtained when the paralyzed monkeys were either dead or prostrate. The adrenals, abdominal sympathetic (celiac) ganglia and plexus, the superior cervical sympathetic ganglia, salivary glands (parotid and submaxillary), spinal cord, and olfactory bulbs were all obtained with aseptic precautions and suspensions prepared of them were

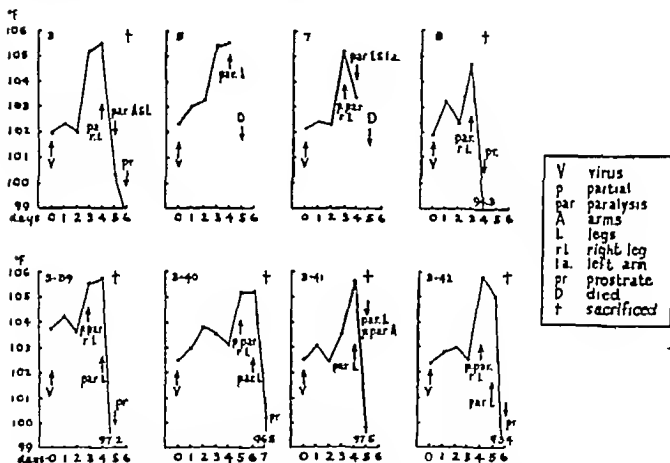


CHART 1 Clinical course of rhesus monkeys inoculated into right sciatic nerve.

injected intracerebrally or intracerebrally and intrapentoneally when sufficient material was available. The nasal mucosa (obtained by a method previously described (8)) the tonsils with the attached pharyngeal tissue, and the small intestine were ground with sand and physiological salt solution and the centrifuged supernatant liquids were treated with 15 per cent of anesthetic ether before intracerebral and intraperitoneal inoculation.

## RESULTS

The clinical course of the experimental disease produced in the 8 monkeys by intrasciatic injection of poliomyelitis virus is shown in Chart 1. It is noteworthy (1) that the incubation period was relatively short, paralysis being observed first on the 3rd day in 3 monkeys, on the 4th day in 4 monkeys, and on the 5th day in 1 monkey, and (2) that the first rise in temperature occurred

TABLE I

*Search for Poliomyelitis Virus in Nasal Secretions of Rhesus Monkeys Inoculated with the "M V" Strain*

Donor monkeys	Period after inoculation	Test on nasal secretions		
		Dose and route	Mon key No	Result
<i>Intrascatic</i> Rh 3—par 4 Rh 5— " 4 Rh. 7— " 3 Rh 8— " 3	days	cc.		
	0 to 1	2 i.c. 1 8 i.p 3 i.n	18	D <sub>2</sub> (pneumonia)
	1 to 2	2 i.c. 3 i.p 3 i.n	19	D <sub>1</sub> (pneumonia)
	2 to 3	2 i.c. 4 i.p 9 i.n	20	Remained well—no poliomyelitis
	3 to 4	2 i.c. 3 i.p 12 i.n	21	" " " "
	4 to 5	2 i.c. 4 i.p 9 i.n	49	D <sub>2</sub> (pneumonia)
	0 to 2	2 i.c. (X 2) 8 i.n	3-61	D <sub>1</sub> —enteritis
	2 to 4	2 i.c. 8 i.n	3 62	D <sub>1</sub> —enteritis—no poliomyelitis
	2 to 4	2 i.c.	2-82	Remained well " "
	4 to 6 (Rh 3-42) 4 to 7 (Rh 3-40)	2 i.c. (X 2) 10 i.n	3-63	" " " "
<i>Intrascatic</i> Rh 3-39—par 3 Rh 3-41— " 4	0 to 2	2 i.c. (X 2) 6 i.n	2-68	" " " "
	2 to 4	2 i.c. (X 2) 6 i.n	3-87	D <sub>2</sub> —pyogenic meningitis
	4 to 5	2 i.c. (X 2) 6 i.n	3-88	Remained well—no poliomyelitis
	5 to 7	2 i.c. 0 5 i.p 6 i.n	2	" " " "
<i>Intracerebral</i> Rh 4—par 5				

i.c.—intracerebral, i.c. (X 2)—reinoculated intracerebrally in 4 to 7 days, i.p—intraperitoneal, i.n—intranasal, par 4—mutual paralysis 4th day after inoculation, D<sub>2</sub>—dead 2nd day

on the same day as the paralysis in 6 monkeys and on the day preceding paralysis in 2 monkeys (to be contrasted with the disease following nasal instillation of the virus when the first rise in temperature occurs 3 to 5 days before the onset of paralysis). The appearance of paralysis first in the inoculated leg of 6 monkeys and in both legs of two others is in accord with the usual course of events. The disease was purposely allowed to run its full course

TABLE II

*Tests for Centrifugal Spread of Virus in Rhesus Monkeys Succumbing with Poliomyelitis Following Intrasciatic Injection of M V Virus*

Tissues tested	Result of test for virus on tissues of donor monkey No.							
	1	2	7	8	3-39	3-40	3-41	3-42
Spinal cord	+	+	+	+	+	+	+	+
Olfactory bulbs	0	0	0	0 [o]	0	0	0	0
Nasal mucosa	0	0	0	0	0	0	0	tu
Tonsils + pharyngeal tissue	0	0	0	tu	0	0	0	0
Salivary glands	0	0 [o]	tu	0	0	0	0	tu
Small intestine	tu	0	tu	0	0	0	tu	0
Abdominal sympathetic-cellac ganglia and plexus	tu	0	0	0	0	0	0	0
Adrenals	0	0	0 [o]	0	0	0	0	0
Superior cervical sympathetic ganglia	0	0	0 [o]	0	0	0	0	tu

0 refers to monkeys whose nervous tissues were passaged to other monkeys with negative results

tu—test unsatisfactory because monkey died of extraneous causes before poliomyelitis could have developed.

in these monkeys in order to permit the greatest possible spread of the virus

The results of the search for virus in the nasal secretions of these monkeys are shown in Table I. While a number of the subinoculated monkeys died of non poliomyelitic causes, a sufficient number survived in the several series to indicate that no virus is demonstrable in the nasal secretions of the intrasciatically infected *rhesus* monkeys during any stage of the preparalytic or paralytic phases of the disease. The tests on the tissues listed in Table II indicate that by the time the terminal phase of the disease is reached or at death the virus had not spread sufficiently either in the central nervous system



to involve the olfactory bulbs and the adjacent nasal mucosa, or peripherally to affect the collateral sympathetic ganglia, such as the superior cervical sympathetic, celiac, or the nerve cells in the adrenals, the collections of nerve cells of the parasympathetic system such as those of Meissner's and Auerbach's plexuses in the small intestine or those in the salivary glands and pharyngeal wall around the tonsils. The negative tests with the tonsils offer confirmatory evidence for the absence of virus in the tissue spaces of the nasal mucosa and other regions whose lymphatics drain into these nodes. The positive results with the spinal cord of each monkey lend weight to the negative tests with the other tissues.

#### DISCUSSION

The results of the present investigation indicate quite clearly the limited spread of "M V" poliomyelitis virus which has invaded the central nervous system of *rhesus* monkeys by way of a peripheral nerve such as the sciatic. While it has been known since Hurst's (11) observations on the histological changes found in intrasciatically inoculated monkeys that the virus invading the lumbar cord rapidly progresses as far as the thalamus and motor cortex, it is now clear that the absence of lesions in the olfactory bulbs of such monkeys, previously noted by Sabin and Olitsky (1) and Bodian and Howe (3), is also associated with an absence of virus. It is also noteworthy that no lesions were found in the anterior perforated substance which was examined in 4 of the monkeys used in the present study. It is interesting and helpful that this correlation between the presence of specific lesions and occurrence of virus obtains in poliomyelitis, since in most of the other neurotropic viruses studied no such correlation has been found chiefly because there usually is widespread dissemination of the viruses in the central nervous system during the terminal phases of the disease. This limited localization of poliomyelitis virus as well as its correlation with the localization of lesions in the central nervous system has recently been found to obtain also in human beings (4).

The negative results with the nasal secretions obtained during various stages of the disease, indicate that there is no justification for the generalization that elimination of virus by the nasal route is one of the consequences of poliomyelitis infection. That these negative results with the nasal secretions and nasal mucosa obtained in *rhesus* monkeys infected by a peripheral neural route with "M V" virus are probably not unique is evident from the fact that similar results were recently obtained in studies on human poliomyelitis (4). The direct demonstration by Lennette and Hudson (17) and the indirect indications from the experiments of Armstrong (18) and of Sabin and Olitsky (1), that poliomyelitis virus may be eliminated on the nasal mucosa following intravenous injection of large amounts, apparently have no bearing on the events which take place when infection occurs by peripheral neural routes.

The absence of virus in the collateral sympathetic ganglia, the adrenals, the

salivary glands, tonsils and pharyngeal tissue, and the small intestine with its numerous nerve cells of Meissner's and Auerbach's plexuses, is ample evidence against the assumption that, at least in *rhesus* monkeys infected with the "M V" strain, poliomyelitis virus after multiplication in the central nervous system spreads outward again to affect peripheral collections of nerve cells in various tissues. The recent tests on the same tissues of human beings with poliomyelitis indicated a similar absence of centrifugal spread, and for that reason the frequent finding of the virus in the human pharynx and intestine suggested these sites as the probable usual portals of entry in man (4).

The possibility that with certain strains of poliomyelitis virus in certain hosts, there may occur a more extensive centrifugal spread cannot be evaluated on the basis of existing data and certainly requires further investigation. For instance, in 1914, Flexner, Clark, and Amoss (19) reported two experiments in which virus was demonstrated in the celiac ganglia: (a) in the first experiment the celiac ganglia from 4 monkeys which died after inoculation with the "K" strain of virus were subinoculated into a *rhesus* monkey which developed clinically and histologically typical poliomyelitis, (b) in the second experiment subinoculation of the celiac plexus from a single monkey succumbing to the "K" virus also produced clinically and histologically typical poliomyelitis. The interpretation of these findings in relation to the question of centripetal versus centrifugal spread depends, however, on whether the monkeys from which these ganglia were derived were inoculated only intracerebrally or intraperitoneally as well. For if the donor monkeys had been inoculated only by the intracerebral route these findings would indicate a centrifugal spread to the collateral sympathetic (celiac) ganglia, if, on the other hand, they had also received virus intraperitoneally the virus may have been present in the celiac ganglia as a result of centripetal invasion. Bodian and Howe (3), for example, observed that lesions in the parasympathetic ciliary ganglia were present in monkeys succumbing after intraocular inoculation ("M V" virus) but not after infection by other routes. Similarly one of us found no lesions in the superior cervical sympathetic and celiac ganglia of 5 *rhesus* monkeys infected intranasally with "M V" virus, while after intraocular injection with the same strain of virus in the same species of monkey Bodian and Howe (3) found occasional lesions in the superior cervical sympathetic ganglia (which contain the sympathetic neurons supplying the eye) in unoperated animals and numerous lesions in monkeys whose ciliary ganglia were removed prior to infection. The recent report of Burnet and Jackson (20) that they found the virus in the sympathetic chain in 2 of 4 *cynomolgus* monkeys which had been inoculated intracerebrally or intraocularly with a strain of virus (Mar) of recent human origin may perhaps be indicative of a certain degree of centrifugal spread to the paravertebral sympathetic ganglia. However, if the sympathetic chain which they tested included the cervical sympathetic ganglia and if the positive results were obtained in the animals which

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were inoculated intraocularly, the virus might have spread there centripetally along the sympathetic fibers and neurons connecting the eye with the central nervous system rather than centrifugally

In view of the high incidence of positive virus isolations from the stools of human beings with poliomyelitis, and the demonstration that the virus is present in the intestinal wall of patients dying of the disease (4), it is of considerable importance to know whether or not poliomyelitis virus can reach the intestinal wall or stools as a result of centrifugal spread from the central nervous system. Clark, Roberts, and Preston (21), Howe and Bodian (22), and Toomey (23) reported negative results in tests on the stools of a total of 17 *rhesus* monkeys which were paralyzed as a result of intracerebral inoculation of "M V" virus. These negative results are especially significant in view of the demonstration by several investigators that poliomyelitis virus can pass through the alimentary tract of *rhesus* monkeys without being inactivated (21), and the finding in the present investigation that demonstrable amounts of virus do not spread to the intestinal wall from the central nervous system.

In an attempt to determine whether the same would obtain for a strain of virus of recent human origin and for *cynomolgus* monkeys, we have made some preliminary tests by searching for virus in the colon contents of 3 paralyzed *cynomolgus* monkeys, inoculated intracerebrally with our 1940 "Per" strain, and obtained negative results. In 1939, Kramer, Hoskwith, and Grossman (9) reported that they tested separately the contents of the small and large intestines (plus, in each instance, some of the mucosa obtained by curettage) of 7 *rhesus* monkeys some of which received the "M V" virus intracerebrally and others the "Armstrong" virus intranasally. While the contents from the large intestine were negative in each case, they found virus in one instance in the contents of the small intestine. It would be easier to interpret the significance of this positive finding if we knew whether or not it occurred in a monkey which had received the "Armstrong" virus (presumably a strain of more recent human origin) intranasally (and therefore also swallowed). In work which we have recently completed on *cynomolgus* monkeys which developed paralysis after being fed a strain of virus of recent human origin ("Per") we had no difficulty in demonstrating virus in the wall and contents of the small intestine (24). The possibility that strains of recent human origin may behave similarly in *rhesus* monkeys is now under investigation.

#### SUMMARY AND CONCLUSIONS

1 Eight *rhesus* monkeys with experimental poliomyelitis following intrasciatic inoculation of "M V" virus were used to study the extent of virus spread in the central and peripheral nervous systems and the question of its elimination in the nasal secretions.

2 Tests on nasal secretions collected on absorbent cotton plugs daily and

continuously from the moment of inoculation to the end of the disease failed to reveal virus

3 No virus was found in the olfactory bulbs, nasal mucosa, tonsils and adjacent pharyngeal tissue, salivary glands, adrenals, superior cervical sympathetic ganglia, abdominal celiac ganglia, and small intestine

4 Elimination of virus by the nasal route was not one of the consequences of poliomyelitis infection resulting from invasion of the "M V" virus by way of a peripheral nerve in *rhesus* monkeys

5 No indiscriminate widespread dissemination of virus occurred in the central nervous system of the intraneurally inoculated *rhesus* monkeys nor did the virus spread outward sufficiently to involve the collateral sympathetic ganglia or the collections of nerve cells in various peripheral tissues. Under certain circumstances, therefore, the presence of virus in these ganglia and tissues may be used as an index to the portal of entry of the virus

#### BIBLIOGRAPHY

- 1 Sabin A. B. and Olitsky, P. K., *J Am Med Assn*, 1937, 108, 21
- 2 Sabin, A. B., *J Am Med Assn*, 1938, 111, 605
- 3 Bodian D., and Howe, H. A., *Brain*, 1940, 63, 135
- 4 Sabin, A. B., and Ward, R., *J Exp Med*, 1941, 73, 771
- 5 Flexner S. and Lewis, P. A., *J Am Med Assn*, 1910, 54, 535
- 6 Landsteiner, K., Levaditi, C., and Danulesco, V., *Compt rend Soc biol*, 1911, 71, 558
- 7 Levaditi C., and Danulesco, V., *Compt rend Soc. biol*, 1912, 72, 651
8. Sabin, A. B., and Olitsky, P. K., *J Exp Med* 1938, 68, 39
- 9 Kramer S. D., Hoskwith, B., and Grossman, L. H., *J Exp Med*, 1939, 69, 49
- 10 Yoffey J. M., and Drinker, C. K., *J Exp Med*, 1939, 70, 83
- 11 Hurst, E. W., *J Path and Bact*, 1930, 33, 1133
- 12 Pette, H., Demme, H., and Körmey St., *Deutsch Z Nervenheilk*, 1932, 128, 125
- 13 Harrison J. A. and Woolpert, O. C., *J Infect Dis*, 1939, 65, 214.
- 14 Toomey, J. A., *Am J Dis Child* 1940, 60, 548, also discussion of paper in *J Bact*, 1940, 39, 64.
- 15 Sabin, A. B., Ward, R., Rapoport S., and Guest G. M., *Proc Soc Exp Biol and Med*, 1941, in press
- 16 Sabin A. B., and Ward, R., *J Exp Med*, 1941, 74, 519
- 17 Lennette E. H., and Hudson, N. P., *Proc Soc Exp Biol and Med*, 1935, 32, 1444.
- 18 Armstrong, C., *Pub Health Rep U S P H S* 1936 51, 241
- 19 Flexner, S., Clark, P. F., and Amoss H. L., *J Exp Med*, 1914, 19, 205
- 20 Burnet F. M. and Jackson A. V., *Australian J Exp Biol and Med Sc.*, 1940 19, 361
- 21 Clark, P. F., Roberts D. J., and Preston W. S., *J Prevent Med*, 1932, 6, 47
- 22 Howe, H. A., and Bodian, D., *Proc. Soc. Exp Biol and Med*, 1939, 41, 538
- 23 Toomey J. A., *Arch Pediat*, 1939 56, 693
- 24 Sabin A. B., and Ward, R., *Science* 1941, 94, 113



# A COMPARISON OF ERYTHROCYTE SEDIMENTATION RATES AND ELECTROPHORETIC PATTERNS OF NORMAL AND PATHOLOGICAL HUMAN BLOOD

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The suspension stability of blood, as measured by the rate of sedimentation of erythrocytes in plasma, has had wide application in medicine since Fåhræus (1) published the results of his investigations on the subject some twenty years ago. It is well known that the sedimentation rate is increased markedly in many pathological conditions, notably in acute infections. However, although a voluminous literature has grown, dealing with many aspects of this subject, the mechanism responsible for the observed differences in the sedimentation rates of normal and pathological blood is not well understood.

Various workers have called attention to an apparent correlation between increases in the sedimentation rate and corresponding increases in serum globulin or fibrinogen levels. An excellent survey of the subject was made by Ham and Curtis (2), in which they discussed various techniques for measuring sedimentation rates, the influence of erythrocyte size and total volume on the rate of fall, and correlation with fibrinogen levels.

In this paper, we shall report the results of studies on human blood in a number of pathological conditions, obtained by the method of electrophoresis. These results have been correlated with corresponding observations on the erythrocyte sedimentation rates.

## *Materials and Methods*

Sedimentation rate measurements were performed on samples of blood<sup>1</sup> taken into tubes containing a dry mixture of potassium and ammonium oxalates, as recommended by Heller and Paul (3). In some cases heparin (Connaught Laboratories) was used as an anticoagulant instead of the oxalate mixture, about 0.1 mg. of this material was sufficient for 10 cc. of blood. After thorough but gentle mixing the blood was introduced into Rourke-Ernstene (4) tubes, graduated at 2 mm. intervals over a length of 100 mm. containing about 1.25 ml. The tubes were suspended in an accurately vertical position in a glass cylinder of water the temperature of which

<sup>1</sup> Fasting samples of blood were drawn from the antecubital vein with as little stasis as possible. The sedimentation rate was measured within 2 hours after collection.



remained quite constant, the work being done in a thermostated room at 25°C. Readings of a clock were taken as the erythrocyte boundary came to succeeding graduation marks. The region of uniform rate of fall determined the (uncorrected) sedimentation rate. The partial volume occupied by the cells (hematocrit) was measured after centrifuging the tubes for 30 minutes at 3000 R P M. The corrected sedimentation rate<sup>2</sup> was then obtained with the aid of charts published by Rourke and Ernstone (4).

Electrophoretic studies were carried out in the Tiselius apparatus, using the scanning method of Longsworth (5). The technique has been described in detail by Longsworth, Shedlovsky, and MacInnes (6). All the determinations were made in diethylbarbiturate buffer solutions at pH 7.8-7.9 and an ionic strength of 0.05, on samples of plasma or serum which had been diluted with 3 volumes of buffer solution against which they were then dialyzed.

### RESULTS AND DISCUSSION

In the paper to which we have just referred (6), electrophoretic determinations were made on the plasma or serum from a number of normal individuals, as well as on that of patients suffering from aplastic anemia, rheumatic fever, pneumonia, peritonitis, peritonsillar abscess, acute lymphatic leukemia, lymphogranuloma, obstructive jaundice, lipoid nephrosis, and multiple myeloma. The corresponding sedimentation rates were determined by us, but were not published at that time. The present electrophoretic studies have extended the work to include more normals and cases of tuberculosis, coronary thrombosis, duodenal ulcer, nephritis, arthritis, lymphosarcoma, burns, fractures, and chemically induced shock in treating insanity. The results are summarized in Table I, and some of the corresponding electrophoretic patterns are shown in Figs. 1 and 2. In columns 7 to 10 of the table are given the values for the ratios of  $\alpha$  globulin,  $\beta$  globulin,  $\gamma$  globulin, and  $\phi$  (fibrinogen) to albumin, respectively. The concentrations of albumin in the plasma (or serum) appear in column 5, and the albumin globulin ratios in column 6. The corrected erythrocyte sedimentation rates (E S R) are listed in column 11. The concentrations of the various components were obtained from the areas under the corresponding electrophoretic peaks, such as are shown in Figs. 1 and 2. The values found for the normals in the present series agree closely with those found by Longsworth, Shedlovsky, and MacInnes (6). It was pointed out by these authors that the most striking and general change in the electrophoretic patterns of pathological serum is reflected in the  $\alpha$  globulin levels, which appear

<sup>2</sup> The rate of fall of particles in a fluid contained in a tube of finite length is determined in part by the partial volume of the particles, since they fall against a counter-current of the fluid which must rise to replace the space formerly occupied by the particles. The counterforce thus exerted against the falling particles depends on the relative volumes of the particles and of the fluid.

to be significantly increased in cases of various febrile infections. The present results confirm these findings and also indicate that they hold true in cases of

TABLE I  
*Composition of Normal and Pathological Serum and Plasma  
Corrected Erythrocyte Sedimentation Rate*

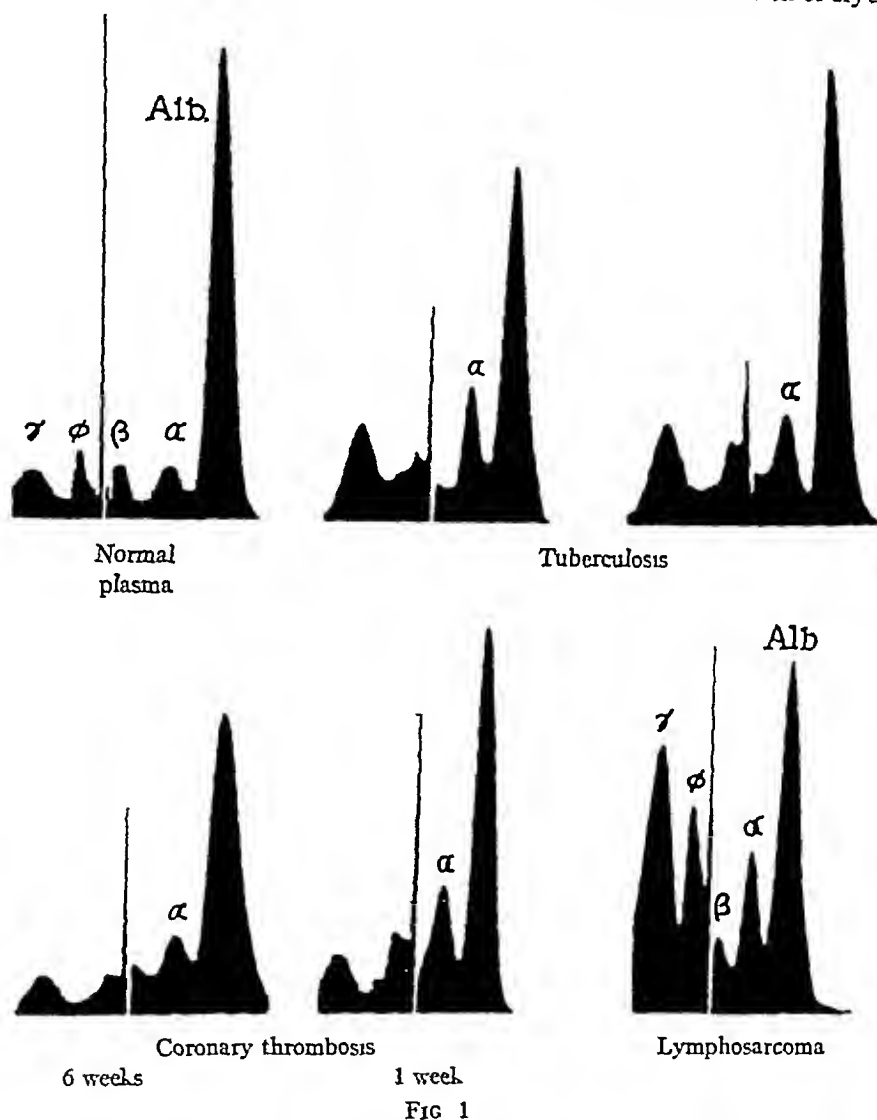
No	Material	Age	Sex	Albu mln	A/G	$\alpha/A$	$\beta/A$	$\gamma/A$	$\phi/A$	S.E.R. mm./ mla	Temp. a.m.	Remarks
				per cent							F	
1	Normal	9	M	3.45	2.27	0.11	0.18	0.15	—	0.10		
2	Normal	40	M	4.06	1.73	0.16	0.23	0.16	—	0.44		
3	Normal	38	F	4.00	2.00	0.14	0.17	0.19	—	0.50		
4	Oligophrenia	38	F	4.66	1.92	0.11	0.18	0.23	0.10	0.40		Phenyl pyruvic acid
5	Psychopathic per sonality	22	F	5.05	2.00	0.16	0.12	0.22	0.07	0.30	99.6	During metrazol shock
6	Schizophrenia simplex	16	F	4.33	2.00	0.17	0.14	0.19	0.10	0.55	96.0	During insulin shock
7	Fracture of tibia and fibula	72	M	3.92	2.13	0.17	0.16	0.14	0.11	0.70	98.6	3 days after accident
8	Fracture of femur	40	M	4.21	1.39	0.21	0.30	0.21	—	1.40	101.2	2 days after accident
9	Burns first, sec ond, and third degree	55	F	3.77	1.04	0.26	0.56	0.25	0.14	2.60	101.0	6 days after accident
10	Duodenal ulcer	58	M	4.55	1.56	0.20	0.25	0.19	—	1.20	98.6	Complicated with hem orrhage and obstruc tion
11	Coronary throm bosis	42	M	3.34	1.07	0.34	0.22	0.27	—	1.40	99.4	1 week after initial attack
12	Coronary throm bosis	43	M	3.40	1.54	0.19	0.30	0.16	—	1.00	98.4	6 weeks after initial attack
13	Tuberculosis	57	M	4.41	1.11	0.19	0.36	0.35	—	1.80	95.6	Chronic pulmonary
14	Tuberculosis	34	M	3.31	0.90	0.34	0.34	0.43	—	1.30	102.0	Bilateral pulmonary far advanced
15	Tuberculosis	39	M	2.95	0.83	0.30	0.34	0.57	0.21	1.80	102.5	Bilateral pulmonary far advanced
16	Tuberculosis	40	M	3.85	1.10	0.17	0.30	0.34	0.10	0.40	100.0	Miliary tuberculous meningitis
17	Tuberculosis	38	M	3.11	1.10	0.33	0.34	0.56	0.24	2.20	100.0	Bilateral pulmonary far advanced
18	Neoplastic disease	36	F	3.80	1.01	0.19	0.29	0.51	—	1.20	95.0	X ray: general skeletal involvement
19	Lymphosarcoma	14	F	3.23	0.70	0.34	0.19	0.91	0.42	1.90	98.0	Febrile Blopey
20	Chronic nephritis	30	F	3.30	1.33	0.30	0.20	0.25	0.10	1.40	98.4	Toxemia of pregnancy Post partum
21	Arthritis	18	F	3.77	1.19	0.34	0.25	0.26	—	3.00	101.4	Gonococcus, 9 day his tory

extensive tissue destruction, as evidenced by the patterns for coronary thrombosis, burns, and fractures<sup>3</sup> (Figs 1 and 2). No significant deviation from normal in either sedimentation rate or electrophoretic patterns was found in the cases (4, 5, 6 of Table I) of chemically induced shock in demented patients.

Various authors have reported that good correlation exists between sedi-

<sup>3</sup> Determinations on the plasmas of three normal individuals whose temperatures were raised by artificial fever to 106 F for 40 minutes showed no increase in  $\alpha$  globulin.

mentation rates and fibrinogen levels (2) However, the addition of purified fibrinogen to normal blood fails to increase the rate of sedimentation of eryth



FIGS 1 and 2 Electrophoretic patterns on normal human plasma and on plasma from individuals with tissue injury from various causes

rocytes to the same extent as one observes in pathological blood containing comparable quantities of this protein In Fig 3, we have plotted the sedimentation rate (E.S.R.) against corresponding levels of fibrinogen expressed as fibrinogen albumin ratios ( $\phi/A$ ), using the results of Ham and Curtis (2)

It will be observed that only a qualitative correlation exists between these two factors

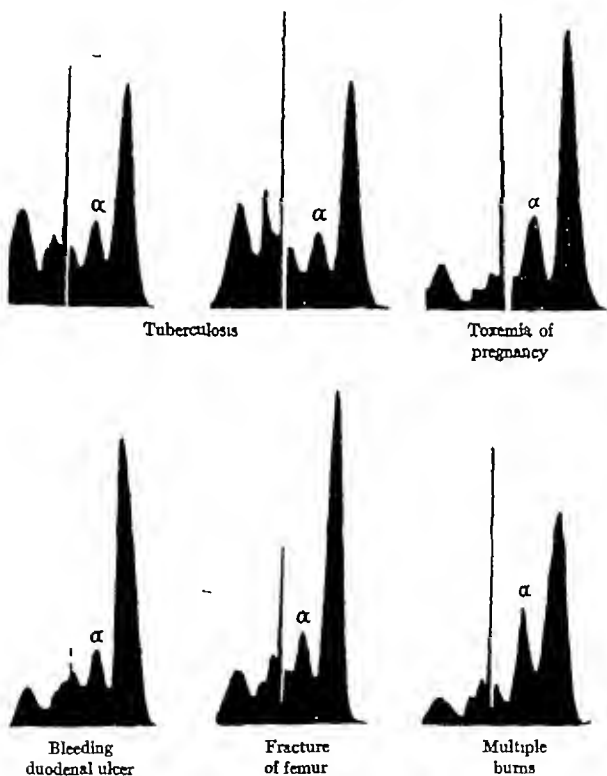


FIG 2

We have found no satisfactory similar correlation with either  $\beta$  globulin,  $\gamma$  globulin, or albumin globulin ratios. However, as will be shown below, a significant correlation can be demonstrated between sedimentation rates and the corresponding  $\alpha$  globulin present in the blood.

In Fig 4 are plotted the  $\alpha$  globulin levels, expressed as  $\alpha$  globulin albumin

ratios, ( $\alpha/A$ ), against the corresponding corrected sedimentation rates (E S R). In this graph have been included points corresponding to the results reported by Longworth, Shedlovsky, and MacInnes (6) as well as our more recent determinations. Although it is not possible to draw a smooth curve through the points indicated, any more successfully than in Fig 3, an in-

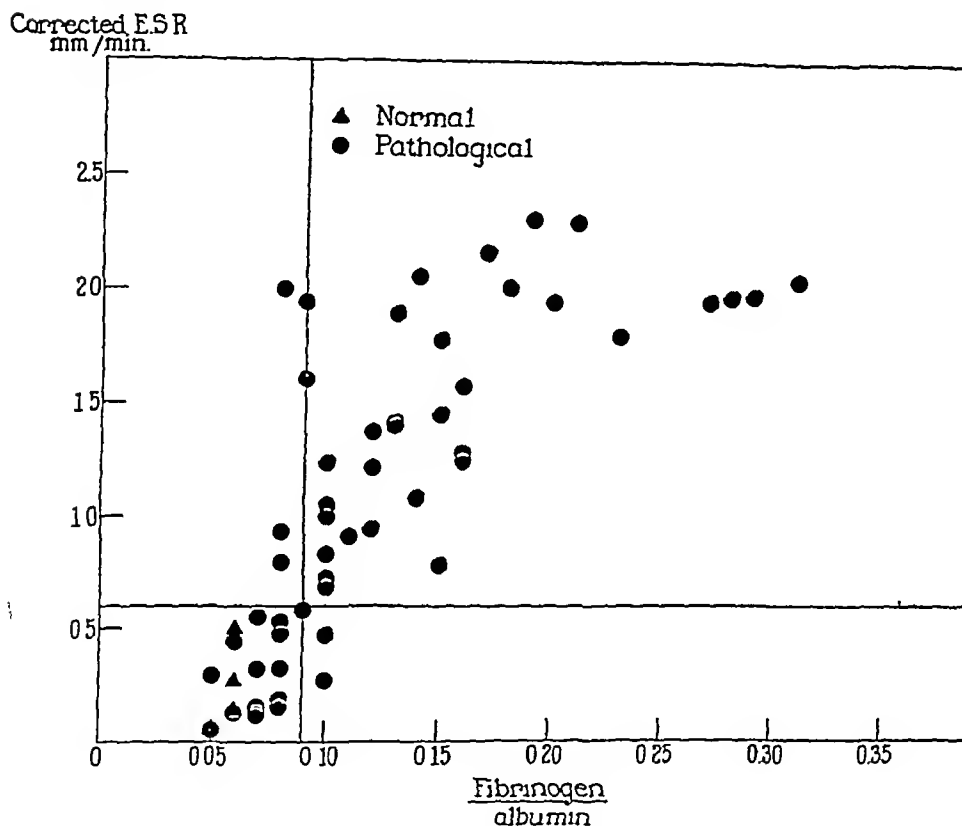


FIG 3 Variation of corrected erythrocyte sedimentation rates with fibrinogen levels

teresting relationship appears. By drawing a horizontal line corresponding to the upper limit of normal sedimentation rate and a vertical line corresponding to the upper limit of normal  $\alpha/A$  values ( $\alpha/A = 0.17$ ), we find all the points corresponding to the normals, as well as those for nearly all the pathological conditions which yield normal electrophoretic patterns, in the lower left hand quadrant. The other points, corresponding to elevated sedimentation rates, fall in the upper right hand quadrant. If we were to draw another vertical line at about  $\alpha/A = 0.20$ , all the points in this more restricted upper right

hand quadrant, with one exception, correspond to febrile conditions. The significance of fibrinogen and of  $\alpha$  globulin in the mechanism responsible for increased sedimentation rates in blood will be discussed in another paper.

Corrected ESR  
mm/min.

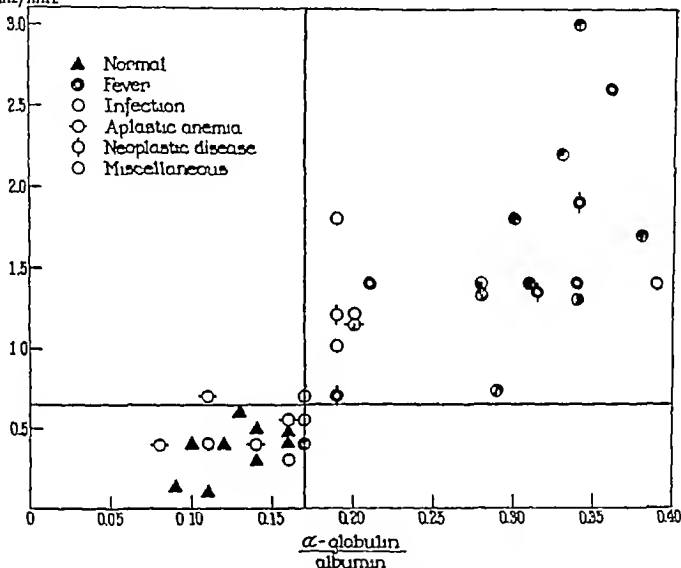


FIG 4 Variation of corrected erythrocyte sedimentation rates with  $\alpha$  globulin levels.

We wish to express our appreciation to the following hospitals for their cooperation: City of New York, Department of Hospitals, Bellevue Hospital, Metropolitan Hospital, Presbyterian Hospital, Rockefeller Hospital, Sloane Hospital for Women, and State of New York, Department of Mental Hygiene, Psychiatric Institute and Hospital.

#### SUMMARY

Electrophoretic studies and erythrocyte sedimentation rate measurements were carried out on normal and pathological human blood. An increase in  $\alpha$  globulin levels appears to take place, as well as an increase in sedimentation

rates, when there is present any considerable inflammation or tissue destruction, irrespective of its cause. A graphic correlation is presented between sedimentation rates and  $\alpha$  globulin levels, which is at least as good as a similar correlation involving fibrinogen levels.

#### BIBLIOGRAPHY

- 1 Fåhræus, R., *Biochem Z*, 1918, 89, 355, *Hygiea*, 1918, 80, 369, *Acta med Scand*, 1921, 55, 1, *Physiol Rev*, 1929, 9, 241
- 2 Ham, T H, and Curtis, F C, *Medicine*, 1938, 17, 447
- 3 Heller, V G, and Paul, H, *J Lab and Clin Med*, 1933-34, 19, 777
- 4 Rourke, M D, and Ernstene, A C, *J Clin Inv*, 1929-30, 8, 545
- 5 Longsworth, L G, *J Am Chem Soc*, 1939, 61, 529
- 6 Longsworth, L G, Shedlovsky, T, and MacInnes, D A, *J Exp Med*, 1939, 70, 399

# STUDIES CONCERNING THE SITE OF RENIN FORMATION IN THE KIDNEY

## I. THE ABSENCE OF RENIN IN THE AGLOMERULAR KIDNEY OF THE MIDSHIPMAN FISH

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### PLATE 1

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The discovery by Tigerstedt and Bergmann (1) of the pressor substance, renin, in the kidney of the rabbit has been amply confirmed. This substance, moreover, has been found to be present in the kidney of every mammal thus far investigated (2-6). The site of renin production or concentration in the kidney is unknown. Goormaghtigh (7-9), on the basis of histological studies of normal and hypertensive kidneys of rabbits and dogs, suggested that renin is secreted by the juxtaglomerular apparatus. On the other hand, Weeks and his associates (10), from their studies concerning the surgical reduction of blood pressure in hypertensive dogs, suggested that the tubule of the kidney is the site of formation of the pressor substance(s). The physiological interdependence of both the glomerular and the tubular vasculature of the mammalian kidney makes the separate assay of either system for renin content difficult. However, the reported absence of glomeruli and significant arterial circulation in the kidney of the toadfish (11) suggested that renin assays of both glomerular and aglomerular fish kidneys might provide a unique opportunity for the determination of the intrarenal site of renin production.

In the present communication, the results of such a study are reported.

### *Description of Experimental Material*

*A. The Midshipman Fish (Batrachoididae, Porichthys notatus)*—The midshipman fish was studied because it was suggested to us by Dr. Homer W. Smith that it might have an aglomerular kidney, as both the midshipman fish and the toadfish belong to the same family (Batrachoididae). Careful histological investigation proved his suggestion to be correct.

The midshipman is a marine fish commonly found along the coast of northern California. It is about one foot in length and has three peculiar and identifying characteristics: (1) when in shallow water it emits a low pitched murmur when irritated or disturbed, (2) it has four body lines consisting of



minute yellow-white circular areas running along its ventral surface, the inner two lines joining each other in a wide circular design, and (3) it has a horny spine at the base of the anterolateral fin and a midline dorsal spine at the anterior termination of the dorsal fin. The small circular areas become luminescent at a high pH.

The kidney's gross anatomical structure is identical with the kidney of the toadfish as described by Marshall (11) except that no renal arterial circulation and no midline fusion of the separate kidneys were discerned. Each kidney weighed about 0.5 gm. On histological examination (Fig. 1) with the aid of Mallory's triple stain, the kidney parenchyma was observed to be composed of two types of cells,—(1) lymphoid tissue cells and (2) tubular epithelium cells. No glomeruli were observed, even on serial section of the entire kidney. The tubular epithelium is of one type, consisting of cells which are cuboidal, equipped with a brush border and a nucleus situated proximally in relation to the tubular lumen.

*B The Carp (Cyprinidae, Cyprinus carpio)*—The kidney of the carp has been described both by Marshall and Smith (12) and by Moore (13). This kidney receives its arterial blood from the metameric arteries arising from the aorta. The glomeruli (Fig. 2) are quite numerous, large, and well lobulated. At the entrance of the arteriole into the glomerulus, an occasional concentration of cells around the arteriole was observed. The nucleus of these cells is vesicular and occasionally surrounded by a halo as described by Kaufmann (14). However, no granules were seen with the Masson trichrome stain, and the exact significance of these cells could not be determined by us. The tubular epithelium appears to be of one type and a brush border was present.

*C The Catfish (Ameiuridae, Ameiurus nebulosus)*—The kidney of this fish also has been described by the previously mentioned investigators (12, 13). Its vasculature and histological structure were observed to be essentially the same as those of the carp kidney. However, the glomeruli did not appear to be as well vascularized and there were fewer juxtaglomerular groups of cells observed in this species of fish.

*D The Hog*—The kidney cortex of the hog was used solely for control purposes. The vasculature, glomeruli, and tubular epithelium of the hog kidney were observed to be essentially similar to those of the human kidney.

#### *Methods of Extraction and Assay*

The extraction of the various types of kidney tissue for renin content was performed with slight modifications according to the method described by Helmer and Page (3).

In brief, 25 to 50 gm. of finely ground, fresh or refrigerated (frozen in this laboratory and stored at  $-40^{\circ}$  or  $-6^{\circ}$ ) kidneys were dehydrated and defatted by two extractions with ice cold acetone and two extractions with ice cold ether at  $0^{\circ}\text{C}$ . The tissue residue was dried in air and pulverized by grinding with sand in a mortar.

Crude extracts were prepared by extracting these powders with three separate portions of 2 per cent sodium chloride solution for 1 hour each at 0°C. After centrifuging, the extracts were combined and poured through a coarse filter paper. A total of 15 cc. of 2 per cent saline solution per gram of fresh kidney was employed but the usual yield after centrifuging and filtering was approximately 1 cc. per gm of tissue. The crude saline extracts were stored at 0°C. until their assay, which took place between 1 and 20 hours after their preparation. The pH was adjusted to 7.0 with sodium hydroxide just prior to their injection into dogs.

In certain experiments the extracts were partially purified and concentrated by extending the process to the stage of Fraction B' of Helmer and Page (3). By this procedure, inert protein was eliminated by adjusting the pH of the crude saline extract to 4.5 with acetic acid. After centrifuging, additional inert material was precipitated by bringing the supernatant fluid to 1 M potassium phosphate concentration (pH 6.5). The mixture was centrifuged and the supernatant fluid adjusted to a concentration of 2 M potassium phosphate solution. After filtering the residue was dissolved in 6 to 10 cc. of 0.9 per cent sodium chloride solution (Fraction B). All procedures except filtration and centrifugation were carried out at 0°C.

Several portions of the glomerular kidney were refrigerated at -40°C. for 14 days because of the difficulty in obtaining sufficient material for complete assay experiments. Control storage of hog kidney and carp kidney, at -40°C. and -6°C., indicated that no significant diminution of the renin content occurred at these temperatures during this period of time.

Five separate extractions of the midshipman fish kidney (A, B, C, D, and E) were performed and the five extracts were tested on three nephrectomized, anesthetized (pentobarbital sodium) dogs. The pressure was obtained by the cannulation and connection of the left femoral artery to a mercury manometer. The introduction of hog kidney extract equivalent to 5 gm. of the fresh material into each dog after the injection of glomerular kidney extract was found to cause a prolonged pressor effect of over 30 mm. of Hg in every dog.

Four separate extractions of the carp kidney (A, B, C and D) were performed, and the four extracts were tested on five dogs, three of which were anesthetized but not nephrectomized. One extraction of the catfish kidney (A) was performed and tested on two normal anesthetized dogs.

Two separate extractions of hog kidney were performed and tested on two anesthetized dogs (one dog was normal). Also previously tested hog extracts were used for the induction of tachyphylaxis in several experiments.

## RESULTS

Despite the fact that five separate extracts of varying quantities of the fresh and refrigerated glomerular kidneys of the midshipman fish were prepared and tested, none of them were observed to exert a pressor effect upon the nephrectomized, anesthetized dog (Table I and Text fig. 1). The crude kidney extracts, however, exerted a slight depressor effect on injection.

Each of the five extracts of the glomerular kidney of the carp was observed to exert a preliminary depressor and then a prolonged pressor effect upon the

anesthetized dog Greater effects were obtained when the dog was nephrectomized prior to the administration of the extract It should be noted (Table I) that a pressor effect was even obtained with an extract equivalent to as little as 4.5 gm of fresh carp kidney Furthermore, it was observed that after the induction of renin tachyphylaxis by the administration of hog renin

TABLE I  
*The Pressor Effect of Extracts of the Glomerular and Aglomerular Kidney*

Test animal	Type of kidney extracted	Amount of kidney tissue extracted	Pressor response	Duration of pressor effect
		gm	mm Hg <sub>1</sub>	min
Dog 1	Midshipman fish (A)*	25.0	0	—
Dog 1	" (B)	32.0	0	—
Dog 2	" (C)	10.2	0	—
Dog 3	" (C)	21.4	0	—
Dog 2	" (D)†	8.8	0	—
Dog 3	" (D)†	20.2	0	—
Dog 3	" (E)†	7.5	0	—
Dog 2	Carp (A)	9.9	88	Over 28
Dog 3	" (A)	4.5	30	" 6
Dog 4§	" (B)	8.0	28	" 7
Dog 5§	" (C)*	20.0	20	" 7
Dog 6§	" (D)¶	8.0	48	" 11
Dog 7§	Catfish (A)	5.0	20	" 10
Dog 8§	" (A)	10	40	" 8
Dog 2	Hog (A)**	5.0	60	" 50
Dog 9§	" (B)	5.0	60	" 9

\* Extraction carried to "Fraction B" stage

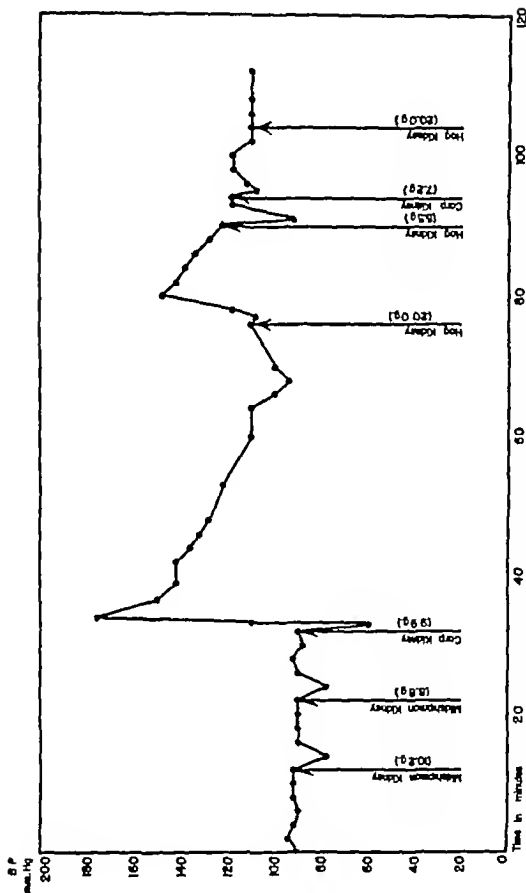
† Stored at -40°C for 19 days

§ Dog not nephrectomized

¶ Stored at -6°C. for 12 days

\*\* Stored at -40°C for 14 days

(Text-fig 1), the carp kidney extract failed to exert a pressor effect In one experiment also, the repeated administration of carp kidney extracts (each extract equivalent to 8.0 gm of fresh kidney) was followed by a typical renin tachyphylaxis In view of the fact that (1) carp kidney extract exerts a prolonged pressor effect typical of renin, (2) is capable of producing renin tachyphylaxis, and (3) is incapable of producing a rise in the blood pressure of a dog after the prior induction of renin tachyphylaxis with hog renin, it appears clear that the pressor activity of the carp kidney is due to its renin content



TEXT FIG 1 The pressor effect of glomerular and glomerular fish kidney extracts upon the nephrectomized dog  
Also the effect of fish glomerular kidney extract after the induction of hog renin tachyphylaxis.

The refrigeration of carp kidney for 14 days at  $-6^{\circ}\text{C}$  was not observed to diminish notably its renin content

The extract obtained from 50 gm of the glomerular kidney of the catfish also was observed (Table I) to exert a prolonged pressor effect (typical of renin), upon a normal anesthetized dog

The administration of an extract equivalent to 5 gm of fresh hog's kidney was found to exert a prolonged and marked pressor effect when given to a normal anesthetized dog (Table I) Furthermore, refrigeration of hog kidney at  $-40^{\circ}\text{C}$  for 14 days did not destroy its renin content

#### DISCUSSION

The foregoing observations indicate that not only the kidney of the hog, but also the glomerular kidney of the catfish and carp contain renin However, repeated assays of the aglomerular kidney of the midshipman fish failed to reveal the presence of any type of pressor substance Thus, although a strongly pressor extract could be obtained from as little as 4.5 gm of fresh carp kidney, a similar assay performed upon 32 gm of fresh midshipman kidney failed to reveal the presence of a pressor substance In view of these findings, it appears clear that the aglomerular kidney of the latter fish contains no detectable renin

The presence of renin in the glomerular kidneys of both the carp and catfish suggests strongly that the absence of renin in the aglomerular kidney of the midshipman fish is due primarily to the fact that the kidney of this last species lacks the arterial vasculature and glomeruli found in the two kidneys first mentioned It strongly suggests, too, that the site of renin manufacture or concentration is not in the tubules of the mammalian kidney

The presence of a juxtaglomerular accumulation of cells in the kidneys of both the carp and catfish has been described No evidence of the possible endocrine activity of these cells, however, could be detected from our limited histological studies

#### SUMMARY

- 1 The absence of glomeruli in the kidney of the midshipman fish (*Porichthys notatus*) is reported

- 2 The detection of renin in the glomerular kidney of the carp, the catfish, and the hog, and the apparent absence of this substance in the aglomerular kidney of the midshipman fish suggest that the tubular portion of the mammalian kidney does not produce or store renin

The authors wish to express their thanks to Dr Homer W Smith of the New York University and to Dr E. K. Marshall, Jr., of Johns Hopkins Medical School who first suggested the use of the midshipman fish Information concerning the fish itself

was given to us by Dr Robert C. Miller of the California Academy of Sciences and by Dr Rolf L. Bolin of the Hopkins Marine Station

We were aided in the histological study of the fish kidneys by Dr G. Rusk of the Mount Zion Hospital

#### BIBLIOGRAPHY

- 1 Tigerstedt, R. and Bergmann P G *Skand Arch Physiol* 1898 8, 223
- 2 Grossman E. B., *Proc Soc Exp Biol and Med*, 1938, 39, 40
- 3 Helmer O M and Page I H., *J Biol Chem* 1939, 127, 757
- 4 Harrison T R., Blalock, A. and Mason M F *Proc Soc Exp Biol and Med*, 1936 35, 38
- 5 Eichelberger L., Leiter, L. and Geiling E M K., *Proc. Soc Exp Biol and Med* 1940 44, 356
- 6 Prinzmetal, M., Lewis H. A., and Leo D L., *J Exp Med* 1940 72, 763
- 7 Goormaghtigh N., *Proc Soc Exp Biol and Med*, 1939 42, 688
- 8 Goormaghtigh N., *Proc. Soc. Exp Biol and Med* 1939, 42, 227
- 9 Goormaghtigh, N *Bruzelles mtd* 1939, 19, 1541
- 10 Weeks D M., Steiner, A. Mansfield, J S and Victor, J., *J Exp Med*, 1940, 72, 345
- 11 Marshall E. K., Jr., *Bull. Johns Hopkins Hosp* 1929, 45, 95
- 12 Marshall E. K. Jr., and Smith, H W *Biol Bull*, 1930 59, 135
- 13 Moore, R. A. Morphology of the kidneys of Ohio fishes, Ohio State University Press Columbus Ohio, Contribution No 5 1933
- 14 Kaufmann W *Proc Soc Exp Biol and Med* 1940, 44, 227

## EXPLANATION OF PLATE 1

FIG 1 The aglomerular kidney of the midshipman fish. Note the absence of glomeruli, and the presence of an abundant round cell stroma between the tubular constituents. Mallory's triple stain  $\times 200$

FIG 2 The glomerular kidney of the carp. There is an abundant stroma composed of red and white blood cells. Note the large and well developed glomerulus. Mallory's triple stain  $\times 200$







## QUANTITATIVE EXPERIMENTS WITH ANTIBODIES TO A SPECIFIC PRECIPITATE

### III. ANTIGENIC PROPERTIES OF HORSE SERUM FRACTIONS ISOLATED BY ELECTROPHORESIS AND BY ULTRACENTRIFUGATION\*

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(Received for publication, October 28, 1941)

The relation of antibodies to each other and to the other serum proteins is a subject of considerable theoretical interest and practical importance. Since antibodies are proteins advantage may be taken of a common property of that class of substances—the ability to act as antigens—in carrying out this comparison. In the first study of the present series (1) rabbits were injected with a washed specific precipitate composed of the Type II pneumococcus specific polysaccharide and the corresponding antipneumococcus serum. As the polysaccharide is non antigenic in the rabbit (2) this procedure is immunologically equivalent to injecting pure antibody protein. The resulting anti-antibody rabbit serum was absorbed quantitatively with a variety of specific precipitates derived from horse serum. In a second paper (3) the data were extended to include the behavior of both horse and rabbit specific precipitates in immune chicken sera.

On the basis of their behavior as antigens the horse antibodies were found to fall into two groups, which corresponded with the immunological classification into antibacterial and antitoxic (prezone) antibodies already noted by Ando (4). The almost identical antigenic properties of the various antibacterial antibodies from horse sera suggested that at least the major portions of the protein molecules must be identical. However from this evidence alone it was not possible to decide whether antibacterial antibodies are normally occurring globulins, slightly modified to enable them to react specifically with the appropriate antigen, or whether they constitute a new antigenic fraction not present in normal serum. Inasmuch as certain fractions containing antibodies have been isolated from immune sera by ultracentrifugation (5, 6) and by

\* The work reported in this communication was carried out under the Harkness Research Fund of the Presbyterian Hospital.

electrophoresis (7) it seemed possible that an immunological study of these and corresponding fractions from normal horse serum might provide further evidence on this point

### *Methods and Materials*

*Ultracentrifuge*—Most of the preparative and all of the optical runs were made in an air-driven ultracentrifuge (8) kindly placed at our disposal by Dr Aura E Severinghaus of the Department of Anatomy of the College of Physicians and Surgeons. Sedimentation constants were determined at room temperatures merely for the purpose of identifying the proteins.

*Electrophoretic Apparatus*—Mobilities were determined in the Tiselius apparatus (9), preferably with the Longworth scanning method, while the Philpot-Svensson cylindrical lens was found convenient in guiding separation procedures. All solutions were dialyzed for at least 2 days in cellophane bags against several changes of buffer at ice box temperatures. The completeness of the dialysis was tested in several instances by calculation of the constancy of the refractive index increments of several dilutions of the protein solution with buffer. The relative refractive index measurements were made with an interferometer.

*Anti-Antibody Serum*—This was the rabbit serum pool used in the earlier studies and resulted from injection of rabbits with a washed specific precipitate derived by reaction of Type II pneumococcus specific carbohydrate with Type II antipneumococcus horse serum H513<sup>1</sup>. Ultracentrifugal and electrophoretic analyses of the serum were carried out, both before and after absorption with polysaccharide.

In electrophoresis no definite peak corresponding to a component migrating between the  $\beta$ - and the  $\gamma$ -components was found in the unabsorbed serum as would have been expected from electrophoretic measurements on certain other anti-Pn horse sera (7). Measurements were made of the area under the curves, the average ratios of the  $\alpha$ -,  $\beta$ -,  $\gamma$ -areas to the albumin area being 0.36, 0.44, and 1.39 for the unabsorbed serum. After absorption with the Type II specific polysaccharide the corresponding ratios were 0.34, 0.37, and 0.72. The decrease in the first two ratios is probably within the experimental error, although the association of a small amount of antibody with the  $\beta$ -fraction is not excluded. It is apparent, however, that in this particular case most, if not all, of the antibody had the mobility of a  $\gamma$  globulin (*cf.* 10) (Table II).

Ultracentrifugal data on a globulin solution from this same bleeding have since been reported elsewhere (11). They indicate<sup>2</sup> that the antibody is quite polydisperse, although most of the antibody had a sedimentation constant of  $s = 18 \times 10^{-13}$  cm per second per dyne, there were appreciable amounts with  $s = 11$  and 30 (Table I).

<sup>1</sup> Obtained through the courtesy of Dr A. B. Wadsworth and Dr H. W. Lyall of the New York State Department of Health Laboratories.

<sup>2</sup> We wish to thank Dr A. M. Pappenheimer, Jr., for his kindness in sending us the complete data before publication. They were made by the Lamm scale method in the Svedberg ultracentrifuge at the University of Wisconsin.



did not exceed 32°C. The jelly deposited during the first centrifugation was resuspended in saline and recentrifuged with the second portion. Both sediments were again resuspended in saline, merthiolate was added to 1:10,000, and the solutions were allowed to stand for a month to permit complete redispersion. An optical run was then made (preparation 2a, Table I). It showed two components, of sedimentation constants  $s = 18$  and  $s = 7$ , the former comprising about 50 per cent of the protein. A portion of this material was kept for quantitative precipitin determinations. The remainder of the solution was again centrifuged in the quantity head at 36,000 R.P.M. for 2½ hours. The resuspended jelly was then allowed to stand for a month before optical analysis (preparation 2b, Table I). The same two components were present but the heavier material had increased about fourfold. An electrophoretic analysis was also performed on this solution (Table II).

*Fractions Obtained by Electrophoresis*—Two samples of normal horse serum were subjected to prolonged electrophoresis in buffers containing 0.15 M NaCl and 0.02 M phosphate at pH 7.6. In one case it was possible to remove a part of the  $\gamma$ -globulin, in another a small amount of  $\beta$ -globulin (*cf.* 13). The  $\gamma$ -globulin solution was redialyzed and run again to provide more accurate mobility data, and to verify the electrophoretic homogeneity (Table II). It proved to be quite homogeneous on ultracentrifugation as well (Table I). A portion of the  $\gamma$ -globulin was also removed from a bivalent (Types I and II) antipneumococcus horse serum H6225 (Table II). Insufficient material was available to permit a determination of the amount of antibody present, but from the sedimentation photographs it was estimated that about 75 per cent of the protein was rapidly sedimenting.  $\gamma$ -Globulin was also isolated from a weak goat Type II antipneumococcus serum, but contained very little antibody. A solution of the  $\gamma$ -globulin from normal pig serum was also available.<sup>6</sup> It did not react with the antiprecipitate rabbit serum when tested at concentrations up to 0.28 mg N per ml of serum. A diluted unfractionated antipneumococcus horse serum was also tested against the rabbit serum.

*Analytical Procedure*—Accurately measured portions of the rabbit antiserum against the horse Type II antipneumococcus specific precipitate were set up at 0°C with varying amounts of the antigens described above. The analytical methods were those described previously (1, 14). The tubes containing the precipitates were allowed to stand in the ice box, with occasional mixing, for 48 hours, followed by centrifugation in the cold.<sup>7</sup> The precipitates were then washed twice with 3 ml portions of cold saline. Nitrogen in the precipitates was determined by a modification of the micro-Kjeldahl method. Tests made on the supernatants indicated whether all of the added antigen had precipitated. In those instances in which it had, the antibody nitrogen was taken as the difference between the total nitrogen found and the added antigen nitrogen. In some cases of incomplete precipitation of the added antigen it was possible to determine the amount of antigen left in the supernatants by setting the latter up with another portion of serum (15). Antibody

<sup>6</sup> Obtained through the courtesy of Dr. Elvin A. Kabat, now of the Neurological Institute, Columbia University Medical Center.

<sup>7</sup> In a refrigerated centrifuge supplied by the International Equipment Company, Boston.

nitrogen was then determined by deduction of the corrected antigen value from the total N (Tables III-VII)

*Qualitative Inhibition Reactions with Sheep Serum*—A portion of the rabbit anti precipitate serum was tested with increasing amounts of unfractionated sheep serum globulin solution. A marked precipitate could be obtained at certain dilutions of the antigen, a large excess completely inhibited precipitation. Three portions of the rabbit antiserum were then set up with the same excess of sheep globulin. One was kept as a control. To another was added an equivalent amount of a solution of normal horse globulin, preparation 2b. The last portion was treated with an amount of goat  $\gamma$ -globulin solution which gave a good precipitate in the absence of the sheep globulin. The tubes were allowed to stand overnight, after which it was found that

TABLE II

*Electrophoretic Mobilities of Antigen Fractions in Buffers Containing 0.15 M NaCl and 0.02 M Phosphate*

Preparation	Descending mobilities $\times 10^4$ cm./volt/sec.			pH	Remarks
	$\alpha$	$\beta$	$\gamma$		
Ultracentrifuged globulin from normal horse serum, preparation 2b	-2.4	-1.4	-0.7	6.41	
Anti Pn II horse serum H513 unabsorbed	-3.4	-3.0	-0.7	7.55	
Same after absorption with S II	-4.0	-3.2	-0.6	7.55	$\gamma$ Fraction markedly decreased
$\gamma$ -Globulin from normal horse serum			-1.3	7.60	Single component
$\gamma$ -Globulin from immune serum			-0.7	7.49	Single component
$\gamma$ -Globulin from goat serum			-1.2	7.61	Single component

precipitation had occurred only in the tube containing the added normal horse globulin. It was evident therefore that an excess of sheep globulin can completely inhibit the cross-reaction of the rabbit anti-specific precipitate serum with goat  $\gamma$ -globulin. There was apparently no inhibition of the homologous reaction.

#### FINDINGS AND DISCUSSION

In recent years much information has become available on the physical properties of horse serum proteins. Ultracentrifugal analysis has shown the presence of several globulin components in normal horse serum. The largest in amount is contained in the component with a sedimentation constant,  $s$ , of 7, with traces of heavier protein of  $s = 11, 18$ , or 32 (12). In antipneumococcus horse serum the concentrations of the heavier fractions, particularly that of  $s = 18$ , are markedly increased. Most of this new material is antibody (5, 6).

Another type of analysis can be made with the aid of electrophoretic methods. Tiselius has shown (16*a*) that there are at least three globulin components in normal horse serum. Of these, the  $\alpha$ -,  $\beta$ -, and  $\gamma$ -globulins are characterized by mobilities of  $-3.8$ ,  $-3.1$ , and  $-1.0 \times 10^{-5}$  respectively, in buffers of ionic strength 0.15 at pH 7.7. Tiselius and Kabat have reported (7) the antibody in antipneumococcus horse sera to have a mobility of  $-1.6$  to  $-1.8$  under the same conditions, although some sera showed an additional antibody of lower mobility,  $-0.3$  to  $-0.9$ . Moore, van der Scheer, and Wyckoff on the other hand found (10) that all of the antibody in their antipneumococcus sera had a mobility corresponding to that of the  $\gamma$ -globulin. Confirmation of the presence of antibody migrating between the  $\beta$ - and  $\gamma$ -components in other sera has been made however (17).

Relatively few studies have been made on the sedimentation constants of material isolated by electrophoresis, or the mobilities of fractions prepared by ultracentrifugation. Tiselius has reported (16*a*) that horse serum albumin obtained by electrophoresis had the same sedimentation constant as crystalline serum albumin, and that normal horse  $\gamma$ -globulin is also practically homogeneous, with  $s = 7.0 \times 10^{-13}$ . The  $\alpha$ - and  $\beta$ -globulins examined were more complex, in addition to the main components of  $s = 6.7$ , there were others with  $s = 3.1$  and  $18$  (*cf.* also 16*b*). Electrophoresis of purified antipneumococcus horse antibody solutions which showed polydisperse material in the ultracentrifuge revealed the presence of increased amounts of material of mobility  $\mu = -0.3$  to  $-0.9$ , as well as the component  $\mu = -1.7$  previously identified as antibody (7). The  $\gamma$ -globulin from normal horse serum has recently been shown to be inhomogeneous with respect to solubility (18).

In the present study information was desired on the immunological properties of fractions in normal horse serum which corresponded in physical properties with components present in immune sera. It was first established<sup>2</sup> that the major part of the antibody in the horse serum H513, from which the immunizing specific precipitate was derived, was rapidly sedimenting (Table I). The rabbit antiserum to horse anti-Pn II (anti-antibody serum) therefore contained antibody directed against a protein of high molecular weight. Electrophoretic study of H513 showed that the antibody was mainly in the  $\gamma$ -globulin fraction.

Since it has been established that normal horse serum contains a small amount of a high molecular weight component of the same sedimentation constant as antibody (12, 5) it was attempted to isolate enough for comparison with the antigenic properties of antibody fractions. Sera from two normal, unimmunized horses were used. By differential ultracentrifugation it was possible to free most of the rapidly sedimenting material from the lighter components (preparations 1 and 2*a*, *b*). The analytical control of preparation 2 was the more complete, and the product was purer, although neither lot was homogeneous (Tables I and II.)

Both preparations were set up against the rabbit anti-antibody serum. Preparation 1 removed only about one half of the total antibody present (Table III). Preparation 2a precipitated more of the antibody, and after further ultracentrifugation precipitated practically all of the antibody N from the

TABLE III

*Precipitation of Rabbit Anti Pn II Horse Specific Precipitate Serum by Heavy Components of Normal Horse Serum per 1.0 Ml Serum 0°C., 48 Hours*

Antigen N added	Antigen N pptd.	Total N pptd.	Antibody N pptd.	Antibody N / Antigen N ratio in ppt	Tests on supernatants
mg	mg	mg	mg		
Test antigen ultracentrifuged globulin from normal horse serum, preparation 1					
0.041†	Total	0.170	0.129	3.1	Excess antibody, no antigen
0.068	'	0.236	0.168	2.5	'
0.095‡	'	0.284	0.189	2.0	"
0.136	0.129‡	0.360	0.231	1.8	Slight excess antigen
0.181	0.151‡	0.356	0.205	1.4	Excess antigen
Mg. antibody N pptd. = 4.9 (antigen N) - 9.0 (antigen N) <sup>1/2</sup>					
Test antigen ultracentrifuged globulin, preparation 2b					
0.026‡	Total	0.192	0.166	6.4	Excess antibody no antigen
0.034**	'	0.249	0.215	6.3	'
0.051‡	'	0.326	0.275	5.4	'
0.102	'	0.510	0.408	4.0	'
0.153	(0.150)	0.610	(0.460)	(3.1)	Traces antigen and antibody
0.204	'	0.638‡‡	'	'	Excess antigen no antibody
Mg. antibody N pptd. = 9.0 (antigen N) - 15.5 (antigen N) <sup>1/2</sup>					

\* Assuming all of the antigen N to be precipitated.

† Single determination only.

‡ From analysis of the supernatant.

‖ Quadruple quantities of antigen and serum used for analysis to insure greater accuracy.

\*\* Triple quantities used.

‡‡ Double quantities used.

‡‡‡ Supernatant gave no precipitate with salt-dissociated Pn I antibody solution.

rabbit serum (preparation 2b, Table III). This indicated that the heavy protein which now constituted the bulk of the preparation was the active antigen, the lighter components in preparation 2a having possibly caused partial inhibition. A comparison of the antigenic properties of these materials with other antigens including the salt-dissociated antibody solutions studied previously (1) is given in Fig. 1.



It is evident that preparations isolated by similar procedures from two different samples of presumably normal horse serum have dissimilar immunological properties. In the one instance a product with antigenic properties approaching those of the original pneumococcus anticombohydrate was obtained. This finding raises the question whether a horse with no previous

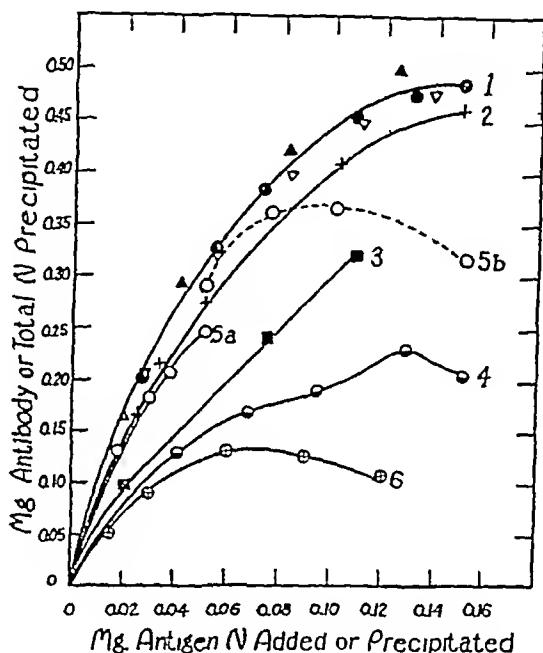


FIG 1 Precipitation of an anti-antibody rabbit serum by various antigens. Curve 1, ● = Pn I, II horse  $\gamma$ -globulin, ▲ = Pn II salt-dissociated antibody solution (1), ▽ = Pn I salt-dissociated antibody solution (1), Curve 2 = normal horse heavy globulin, preparation 2b, Curve 3 (total N precipitated) = normal horse  $\beta$  globulin, Curve 4 = normal horse heavy globulin, preparation 1, Curve 5a = normal horse  $\gamma$ -globulin, Curve 5b (total N precipitated) = normal horse  $\gamma$ -globulin, Curve 6 (total N precipitated) = goat  $\gamma$ -globulin

history of immunization might not at some time have been subjected to an unrecognized infection sufficient to induce antibody formation. The problem could only be solved by extensive experiments.

Less uncertain are the differences in antigenic behavior between a normal  $\gamma$ -globulin and  $\gamma$ -globulin containing antibody (Table IV). In this instance two serum proteins which have the same electrophoretic mobility and are homogeneous by that physical criterion can be distinguished from each other by a second physical method, ultracentrifugation, and by the immunological

method (Tables I, II, IV, and Fig 1) An interpretation of this behavior in terms of the quantitative reaction constants is given below

A sample of the low molecular weight  $\beta$ -globulin from normal horse serum also cross-reacted with the anti-specific precipitate rabbit serum (Table V)

TABLE IV  
*Precipitation of Antibody from Rabbit Anti Pn II Horse Specific Precipitate Serum by Fractions Isolated by Electrophoresis from Normal and Immune Horse Sera per 1.0 Ml Serum 0°C, 48 Hours*

Antigen N added	Antigen N pptd	Total N pptd.	Antibody N pptd	Antibody N / Antigen N ratio in ppt.	Tests on supernatants
mg	mg	mg	mg		
Test antigen $\gamma$ -globulin solution from normal horse serum					
0.018†	Total	0.149	0.131	7.3	Excess antibody, no antigen
0.030†		0.213	0.183	6.1	" "
0.038‡		0.243	0.205	5.4	" "
0.051		0.296	0.245	4.8	" "
0.076	Incomplete	0.354			Both antibody and antigen
0.101		0.356			" "
0.152	"	0.306			" "
Mg antibody N pptd. = 10.8 (antigen N) - 26.6 (antigen N) <sup>43</sup>					
Test antigen $\gamma$ -globulin solution from an antipneumococcus horse serum					
0.027‡	Total	0.229	0.202	7.5	Excess antibody, no antigen
0.055	Total	0.381	0.326	5.9	" "
0.073		0.456	0.383	5.2	" "
0.110	0.103**	0.562	0.454	4.2	Excess antibody, trace antigen
0.137	0.131**	0.606	0.475	3.6	Trace antibody and antigen
Mg antibody N pptd. = 10.8 (antigen N) - 19.8 (antigen N) <sup>43</sup>					

\* Assuming that all of the added antigen is precipitated.

† 2.5 times this quantity of antigen and serum used for analysis.

‡ Double quantities used.

|| One and one half quantities used.

\*\* From analysis of supernatant.

A complete curve could not be constructed as the sample was antigenically inhomogeneous, but the data differentiate it clearly from the antibody containing fractions. An attempt was also made to study the immunological behavior of antibody migrating faster than the  $\gamma$ -component, but in two sera which contained appreciable amounts of this component a portion of the antibody occurred in the  $\gamma$ -globulin fraction as well (cf 6). A specific precipitate

made from one of these sera had practically the same quantitative properties as the  $\gamma$ -antibody specific precipitates (1). Another form of antipneumococcus horse antibody having a molecular weight of 150,000 has recently been reported (11). No samples were available.

Marrack and Duff (19) concluded that a whole globulin solution from normal horse serum removed only a portion of the antibody from anti-specific precipitate serum. However, when we used whole antipneumococcus horse serum as antigen the total N precipitated corresponded to that expected from the antibody content of the serum (*cf* 4).

It will be noted from Fig. 1 that antipneumococcus Types I and II horse antibodies isolated by salt dissociation and used as antigens follow closely the curve for the  $\gamma$ -globulin from an antipneumococcus horse serum. The data may be expressed by an equation which has been found to represent satis-

TABLE V

*Precipitation of Antibody from Rabbit Anti-Pn II Horse Specific Precipitate Serum with Normal Horse  $\beta$ -Globulin per 10 Ml Serum, 0°C, 48 Hours*

Antigen N added	Antigen N pptd	Total N pptd	Antibody N pptd	Tests on supernatants
mg	mg	mg	mg	
0.020	Total	0.10	0.08	Excess A, no antigen
0.072	Incomplete	0.24	(0.17)	Excess antigen, no A
0.109	"	0.32	(0.22)	Excess antigen, no A

Single determinations only

factorily the behavior of a number of other protein-antiprotein systems (20, 21, 1).

$$\text{mg antibody N precipitated} = k_1 (\text{antigen}) - k_2 (\text{antigen})^{3/2} \quad (1)$$

This equation must be regarded as empirical, for it is not yet possible to give the constants definite chemical and immunological significance as is the case with the second power relation derived for a number of other systems (14, 21). Several conclusions may be drawn, however, when reactions show identical constants. The variation in the constants for the reactions of the  $\gamma$ -globulin solution (Table IV) and the salt-dissociated antibody solutions (1) are within the limits of experimental error. This would indicate that no significant change in antigenic properties had occurred during the chemical treatments with salt. The somewhat lower constants for the reaction of the heavy normal globulin, preparation 2b, (Table III) are probably due to other antigens of lesser reactivity still remaining (see p. 141).

If the equations for the above are compared with that for the reactivity of the normal horse  $\gamma$ -globulin with the same anti-antibody serum it will be noted (Table IV) that the decrease in precipitating power of the normal globulin to

about one-half of the others is reflected in the different reaction constants obtained. If, however, the equations for the normal and immune  $\gamma$ -globulins are recalculated<sup>8</sup> to the same maximum of 1.0 mg. of antibody N removed, the constants of the equations become identical (Table VII), the equation being expressed as

$$\text{mg. antibody N precipitated} = 10.8 (\text{Gb N}) - 13.6 (\text{Gb N})^{2/3} \quad (2)$$

where Gb N is the amount of normal or immune  $\gamma$ -globulin nitrogen. The reactivity of the normal horse  $\gamma$ -globulin *per mg. of antibody precipitated* is therefore the same as that of the immune  $\gamma$ -globulin antigen, and it is evident that the portion of the rabbit antibody which is precipitated by both globulins is incapable of distinguishing between them. The remaining portion of the antibody precipitates only the immune globulins or the heavy normal horse protein. These findings may be compared with others from this laboratory, in which it was noted that a cross-reacting antibody solution reacted equally well with two different pneumococcus specific polysaccharides (22) or that serum supernatants from the absorption with heterologous polysaccharide (23) or specific precipitate (1) still yielded the same reaction curve with the homologous antigen as did the original serum, when calculated to the same antibody content.

The following hypothesis may be advanced to account for the cross reaction of normal horse  $\gamma$ -globulin with antisera to the  $\gamma$ -globulin from immune sera. The chemical composition of antibodies and normal globulins from the same species appears to be quite similar (24). The striking differences between the two  $\gamma$ -globulins are the sedimentation constants and therefore the molecular weights, approximately 150,000 and 910,000. If the large size of the immune  $\gamma$ -globulin were due to a polymerization of six specifically altered  $\gamma$ -globulin units, it might account for the cross-reaction of a single normal  $\gamma$ -globulin unit with antiserum toward the polymerized molecule. Such specific groups on the antibody  $\gamma$ -globulin molecule as are responsible for its function as an antibody need not be taken into account here since they apparently are not antigenic (1, 3).

If this view were correct, the cross-reaction of the normal horse  $\gamma$  globulin with an antiserum to the larger immune  $\gamma$ -globulin would be analogous to the precipitation of horse antisera to undegraded pneumococcus carbohydrate by various degraded pneumococcus polysaccharides (25). In Table VII are given

<sup>8</sup> The amount of antigen required to precipitate the calculated maximum amount of antibody, A, may be found by differentiating equation (1) with respect to the antigen and equating to zero (*cf.* 21). Specifically equation (2) becomes  $10.8 - 3/2 \times 13.6 (\text{Gb N})^{1/3} = 0$ , and is solved for Gb N. Substitution of this new antigen value in equation (1) gives the corresponding maximum A. Conversion to a basis of 1.0 mg. A may be made by multiplying the slope,  $k_1$ , by the  $\sqrt{A}$  calculated above.

data on the reaction of a number of Type III pneumococcus polysaccharides which had been partially hydrolyzed by acids. This treatment is known to break down the polysaccharide chain into shorter units (25) and can be followed by changes in the viscosity or in the amount of reducing groups. It will be noted that in spite of the smaller quantities of antibody precipitated by a given amount of the acid-treated polysaccharides, the reaction constants calculated to a common maximum amount of antibody precipitated (10 mg N) are remarkably similar to each other and to those for the untreated material. In contrast is the behavior of the Type I pneumococcus polysaccharide treated with alkali. Under these conditions changes in the polysaccharide are known to be more complex than simple depolymerization (26, 26). The data avail-

TABLE VI

*Cross Reaction of  $\gamma$ -Globulin from Goat Serum with Antibody from Rabbit Anti-Pn II Horse Specific Precipitate Serum per 10 Ml Serum, 0°C, 48 Hours*

Antigen N added	Antigen N pptd	Total N pptd	Antibody N pptd	Antibody N Antigen N in ppt *	Tests on supernatants
mg	mg	mg	mg		
Test antigen $\gamma$ -globulin of goat serum					
0.015†	Total	0.052	0.037	2.5	Excess A, no antigen
0.030†	Incomplete	0.092			Slight amount antigen and antibody
0.060§	"	0.132			Excess antigen, trace antibody
0.090	"	0.126			Excess antigen
0.120§	"	0.108			" "

\* Assuming all of the added N to be precipitated

† Double quantities of antigen and serum actually used

§ Single determination only

able, while less numerous, are quite concordant and show clearly the marked differences in the reaction curves produced by the action of alkali on this antigen.

A slight cross-reaction with the anti-antibody rabbit serum was observed for the isolated  $\gamma$ -globulin from goat serum (Table VI). No sedimentation data were available for this preparation. Comparison could be made, however, of the relative precipitating powers of two antigenic fractions from two different species toward antisera to one of them. From Tables III and VI it may be estimated that the goat  $\gamma$ -globulin removed about 15 per cent of the antibody toward the homologous (horse) antibody  $\gamma$ -globulin. A preliminary analysis of the cross-reactivity of electrophoretically isolated goat albumin against a rabbit antiserum to crystalline horse serum albumin showed that the antibody N precipitated in the equivalence zone was about 10 per cent of

that removed by the horse albumin.<sup>8</sup> The order of magnitude in the cross reactions between goat antigens and rabbit antisera to the corresponding fractions from horse sera is thus the same.

TABLE VII

*Precipitin Reaction Characteristics with Antibody N Precipitated at One Antigen Level, and Empirical Reaction Constants Calculated to a Maximum of 1.0 Mg of Precipitable Antibody*

Preparation	Antibody N pptd. per ml by given amount of antigen (experimental)	Reaction constants equation (1) per 1.0 mg. maximum antibody	
		Intercept, $k_1$	Slope $k_2$
*†			
Rabbit anti-specific precipitate serum with horse globulin fractions			
	0.05 mg. protein antigen N		
Pn II antibody solution (1)	0 320	10 9	13 9
Pn I antibody solution (1)	0 305	9 9	11 9
Antibody $\gamma$ -globulin	0 310	10 8	13 6
Normal $\gamma$ -globulin	0 240	10 8	13 6
Normal heavy globulin, preparation 1	0 145	4 9	4 1
“ “ preparation 2b	0 270	9 0	10 3
Horse anti Pn III antibody solution and various S III preparations*			
	0.15 mg S III		
Untreated S III	2 12	39 5	95
S III HCl A	1 90	40 0	98
S III, H <sub>2</sub> SO <sub>4</sub> B	1 68	41 4	102
S III HCl C	1 62	40 7	100
S III, HCl D	1 36	39 5	96
S III H <sub>2</sub> SO <sub>4</sub> C	1 30	{ 43 5† 37 0	{ 111† 87
Horse anti Pn I serum and S I preparations‡			
	0.15 mg S I		
S I untreated	0 340	12 8	17 6
S I, treated with alkali at 37°	0 220	10 7	13 5

\* Calculated from (25) and unpublished experiments in this laboratory by Dr. Forrest E. Kendall. The fractions are described in (25).

† Because of the scattering of the points about a straight line the highest and lowest values calculated from the data are given.

‡ From unpublished data by Mrs. H. F. Havas.

The technique most commonly used in determining the degree of zoological relationships is to inject rabbits with the whole serum of one species and to test

<sup>8</sup> The serum used was calibrated by Mr. Manfred Mayer of this laboratory.

the resulting antiserum with whole serum from another species. Interpretation of the results is complicated by a number of factors. Whole serum is a mixture of antigens which may differ considerably in their relative concentrations and in their antigenic powers. An undue proportion of the antibodies produced might therefore be directed toward a minor serum constituent. If this complicated mixture of antigens and their antibodies is examined by the usual dilution methods multiple zones of precipitation often result, with partial or complete inhibition of some of the reacting systems. The use of dilution methods and whole serum would, for example, completely obscure the relation between the antigenic properties of the normal horse  $\gamma$ -globulin and the immune horse  $\gamma$ -globulins traced above.

A more direct method would be to study the antigenic properties of one or more homogeneous fractions isolated by chemical methods or by electrophoresis or ultracentrifugation from the sera to be compared. The interaction between these antigens and their antibodies could then be satisfactorily determined by quantitative absolute methods, such as have already proved useful in comparing the species specificities of mammalian thyroglobulins (27). Further studies along these lines would show whether the percentage of cross-reaction of various serum fractions is constant for related species (as in the instance of the horse and goat albumins and  $\gamma$ -globulins here reported) or variable, with perhaps limiting cases in which only the albumins (or globulins) possessed groupings in common. Whatever the findings, it is possible that this information would be of more fundamental significance for general physiology as well as zoological classification than are the conclusions drawn from the average behavior of complicated mixtures such as whole sera.

It is concluded from the data presented that antipneumococcus antibodies from horse sera resemble in antigenic behavior certain normally occurring horse serum globulins, while they differ in some respects from others having the same sedimentation constant or electrophoretic mobility. Thus the antibodies were practically identical in antigenic properties with a rapidly sedimenting globulin from one sample of supposedly normal horse serum but differed in these properties from a sample with the same sedimentation constant from another horse. Differences in antigenic behavior between the normal and immune  $\gamma$ -globulin of the same electrophoretic mobility were accompanied by differences in sedimentation constants and molecular weights, in accord with quantitative relations among the immune properties suggesting that the differences are but reflections of the variation in chain length.

#### SUMMARY

- 1 Rabbit antisera to a Type II pneumococcus specific precipitate from horse serum were tested with fractions prepared by ultracentrifugation and electrophoresis of normal and immune horse serum

- 2 In one instance a rapidly sedimenting protein from normal horse serum

had nearly the same quantitative antigenic properties toward the anti-antibody rabbit serum as did the purified pneumococcus antibody solutions previously reported. In another instance a comparable fraction removed only a part of the rabbit antibody.

3 Electrophoretic  $\gamma$ -globulin from an immune horse serum had quantitatively the same antigenic properties as did antibody solutions prepared by salt-dissociation of specific precipitates.

4 Electrophoretic  $\gamma$ -globulin from normal horse serum differed in its antigenic behavior from  $\gamma$ -globulin containing antibody. The data are compared with the antigenic properties of acid and alkali treated pneumococcus specific polysaccharides toward antipneumococcus horse sera. An interpretation in terms of polymers is suggested.

5 The cross-reaction of goat serum  $\gamma$ -globulin against the anti-antibody serum is reported and the extent of the reaction compared with those of goat and horse serum albumins against a rabbit antiserum to the latter.

#### BIBLIOGRAPHY

- 1 Treffers, H P, and Heidelberg M. *J Exp Med*, 1941, 73, 125
- 2 a Avery, O T and Neill J M. *J Exp Med* 1925, 42, 355  
b Avery, O T and Goebel W F, *J Exp Med* 1933 58, 731
- 3 Treffers, H P and Heidelberg M. *J Exp Med* 1941, 73, 293
- 4 Ando K, *J Immunol* 1937 83, 41
- 5 Heidelberg M, and Pedersen K O. *J Exp Med*, 1937, 65, 393
- 6 Kabat, E, *J Exp Med* 1939, 69, 103
- 7 Tiselius, A and Kabat E. *J Exp Med*, 1939 69, 119
- 8 Chiles J A. and Severinghaus, A E, *J Exp Med*, 1938 68, 1 *Rev Scient Instr*, 1940 11, 71
- 9 Tiselius, A, *Harvey Lectures* 1939-40 35, 37
- 10 Moore D H, van der Scheer J and Wyckoff, R. W G, *J Immunol*, 1940, 38, 221
- 11 Petermann M L and Pappenheimer A M, Jr, *Science*, 1941 93, 458
- 12 von Mutzenbecher, P. *Biochem. Z.* Berlin, 1933, 268, 226-250
- 13 See Blix, G. Tiselius, A and Svensson, H. *J Biol Chem* 1941 137, 485, for a more recent method
- 14 Heidelberg M., Kendall, F E, and Soo Hoo C M, *J Exp Med* 1933, 58, 137  
Heidelberg M, and Kendall, F E, *J Exp Med*, 1935, 61, 559-563
- 15 Heidelberg, M., and Kendall, F E. *J Exp Med* 1932, 55, 555
- 16 a Tiselius, A. *Biochem J* London, 1937 31, 1464 b Svensson, H. *J Biol Chem*, 1941 139, 805
- 17 van der Scheer J, Lagsden, J B, and Wyckoff, R. W G, *J Immunol*, 1941, 41, 209 Smetana, H and Shemin, D. *J Exp Med*, 1941, 73, 223
- 18 Cohn E J, McMeekin T L, Oncley J L, Newell, J M. and Hughes, W L., *J Am Chem. Soc.* 1940, 62, 3386
- 19 Marrack, J R. and Duff D, *Brit J Exp Path* 1938 29, 271
- 20 Heidelberg M, and Kendall, F E, *J Exp Med* 1935, 62, 467



- 21 Heidelberger, M , and Kendall, F E , *J Exp Med* , 1935, 62, 697
- 22 Heidelberger, M , and Kabat, E A , *J Exp Med* , 1938, 67, 181
- 23 Heidelberger, M , Kabat, E A , and Shrivastava, D L , *J Exp Med* , 1937, 65, 487    Heidelberger, M , Kabat, E A , and Mayer, M , *J Exp Med* , 1942, 75, 35
- 24 Hewitt, L F , *Biochem J* , London, 1934, 28, 2080    Calvery, H O , *J Biol Chem* , 1935, 112, 167    Chow, B F , and Goebel, W F , *J Exp Med* , 1935, 62, 179
- 25 Heidelberger, M , and Kendall, F E , *J Exp Med* , 1933, 57, 373
- 26 Heidelberger, M , Kendall, F E , and Scherp, H W , *J Exp Med* , 1936, 64, 559
- 27 Stokinger, H E , and Heidelberger, M , *J Exp Med* , 1937, 66, 251

## THE LS-ANTIGEN OF VACCINIA

### I INHIBITION OF L- AND S-ANTIBODIES BY SUBSTANCES IN TREATED VACCINE DERMAL FILTRATE\*

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A relationship between the heat labile (L) and heat stable (S) soluble antigens of vaccinia has been shown to exist by several workers. Craigie and Wishart (1) originally regarded the two antigens as occurring in the form of a complex which elicited two separate antibodies in animals. They were led to this conclusion because both antigens regularly are found in equal amounts in filtrates of infected tissue and because absorption with either specific antibody removes both serologically active substances. Parker (2) observed that under certain conditions different results were obtained, e.g., a solution containing both precipitable substances when treated with S-antibody lost its S-antigen but retained some L-antigen. Craigie and Wishart (3), at about this time, made similar observations, they reaffirmed that L-antigen ordinarily occurs in a state of combination with S-antigen but reported that with prolonged storage in the cold "this combination may dissociate into separate L and S fractions prior to ultimate inactivation of the L antigen." The data of Parker and of Craigie and Wishart that suggested dissociation of L- and S-antigens have not been duplicated in our laboratory. This failure we believe indicates that conditions for successful repetition of such experiments occur infrequently. That they do occur occasionally we have no doubt, for, as will be shown in a subsequent paper (4), a solution with L-activity only can be prepared from pure LS-antigen by enzymatic digestion.

In our experience, L-antigen has always been encountered in association with S-antigen except under the special circumstances just mentioned. This was true even though at various times during the past five years we have thought of the L-reacting substance as a protein, a carbohydrate, a fat, or a polypeptide and have attempted to isolate such an hypothetical material from dermal filtrates by appropriate methods. When it became evident that the methods employed were inadequate to procure preparations of L-antigen which were free of S-antigen for comparison with the relatively pure S-protein of Parker

\* Presented in New Haven before the Society of American Bacteriologists, December 29, 1939.

and Rivers (5), other means were sought for the study of the relationship of these two antigens of vaccinia

The inhibition technique used in serological work assisted in establishing the existence of partially degraded forms of the A and B antigens of infectious myxomatosis of rabbits (6). These two protein-like antigens readily lose their specific precipitability on gentle heating or even on storage. Solutions of A-antigen, which are no longer capable of precipitating with A-antibody, still combine with it as demonstrated by the inhibition technique. Solutions of degraded B-antigen behave similarly. Inhibition by the non-precipitable A- and B-antigens is specific, *i. e.*, each antibody combines only with the degraded form of its own antigen. In view of the results obtained with myxoma antigens, inhibition of the L- and S-antibodies of vaccinia was investigated with the hope of demonstrating serologically degraded forms of the L- and S-antigens. It was thought that experimentation with such degraded substances might provide data which would help in interpreting the interrelationship of the two native antigens. The results of these investigations are reported in this paper.

### *Materials and Methods*

*Source of Soluble Antigens*—Dermal filtrate containing the soluble antigens of vaccinia was obtained from dermal pulp of rabbits which had been cutaneously infected 3 days previously with the C L strain of vaccine virus (1). The pulp from each rabbit was suspended in 30 to 40 cc. of a 1:50 dilution of disodium phosphate citric acid buffer solution, pH 7.2. The suspension was freed of gross particles and of essentially all of the elementary bodies of vaccinia by differential centrifugation, and, finally, filtered through a Seitz pad to remove all residual virus. These filtrates were stored at 3°C until used.

*Antisera*—L-antiserum was prepared by absorbing S-antibody from hyperimmune antivaccinal serum. Vaccine virus immune rabbits which had been given a course of intravenous injections of active elementary bodies of vaccinia provided the hyperimmune serum, absorption of S-antibody was carried out with proper amounts of heated dermal filtrate. S-antisera were obtained from non-immune rabbits after several courses of injections of heat-inactivated elementary bodies.

*Precipitin Tests*—0.25 cc. volumes of serial dilutions of solution of antigen were prepared in physiological saline solution buffered at pH 7.2 and mixed with 0.25 cc. amounts of an appropriate dilution of antiserum. Readings were made after incubation overnight in closed tubes held at 50°C.

### EXPERIMENTAL

*General Properties of L-Antigen*—Only a few procedures have been found practicable for the concentration of L-antigen from filtrates of dermal pulp obtained from rabbits infected with the virus of vaccinia. These methods are equally efficacious for the concentration of S-antigen. Craigie and Wishart (1) have observed that both serologically active substances can be obtained

from virus-free dermal filtrate by bringing the pH of the solution to 4.5 and then redissolving the insoluble material thus obtained at pH 6.6. In our hands this method has proved the simplest and the most satisfactory for obtaining solutions containing large amounts of L- and S-antigens from which have been eliminated appreciable amounts of serologically inert material. Moderate variations in the pH ranges employed for precipitating and for redissolving the antigens still result in final solutions with equal amounts of the two serologically active substances, in some instances, however, the recovery of antigenic material is less complete than it is with Craigie and Wishart's technique. Bringing the pH to below 4.0 results in a loss of precipitability of L with its antibody, but S-activity is not appreciably reduced even at pH 1.8. On the alkaline side of neutrality both serological substances retain their activity for many days in the cold at pH 9.0. Furthermore, the L-antigen is unaffected by short exposure to borate buffer of pH 11.0, while the S-antigen is inactivated in N/20 NaOH only after minutes or hours depending on whether the procedure is carried out at 56°C or at 3°C. Treatment with N/20 NaOH rapidly destroys the precipitability of L-antigen.

Under the proper conditions, precipitation of concentrated unheated dermal filtrate with ammonium sulfate yields equal quantities of L- and S-antigen in the globulin fraction. L-activity is generally lost during fractional precipitation with ammonium sulfate unless filtrates which have been concentrated 10 to 20 times by evaporation are used as starting material, preliminary concentrations of dermal filtrate is unnecessary, however, if the objective is purification of S-antigen. Evaporation of dermal filtrate through cellophane sausage casings suspended in an air stream at room temperature provides a ready means of concentrating the soluble antigens, but fails to eliminate any significant amount of serologically inert substances. On the other hand, drying large volumes of dermal filtrate from the frozen state renders some of the inert material insoluble on subsequent resuspension. Although laborious, this procedure can be employed for concentration of the S-antigen, but it is often unsatisfactory for work with L-antigen since temporary thawing during the process may be followed by partial or complete loss of L-precipitability.

The boiling of solutions containing antigens of vaccinia at pH values near neutrality with subsequent removal of coagulated protein has been found by several workers (5, 7, 8) to be of assistance in the partial purification of solutions of the heat-stable antigen, but obviously this procedure has no place in experiments designed for the purification of the heat labile material. Similarly, treatment of dermal filtrate with large volumes of cold alcohol results in complete disappearance of the substance capable of precipitating with L-antibody even though the stable antigen can be recovered from the alcohol insoluble fraction as has been demonstrated by others (5, 8).

The L-antigen of vaccinia may be regarded, therefore, as having certain

properties in common with S-antigen. Both are insoluble in the neighborhood of pH 4.5 and soluble in the region of pH 6.5, and both are found in the globulin fraction when separated from concentrated dermal filtrate by partial saturation with ammonium sulfate. The heat-labile antigen, however, readily loses its specific precipitability under conditions which do not alter the heat-stable antigen, *viz.*, extremes of pH, treatment with alcohol, and, in certain instances, drying from the frozen state or precipitation with ammonium sulfate. The common solubilities of the two antigens gave no clue to their nature, since the data might equally well suggest that the antigens are parts of a single protein molecule, or that they are similar protein substances, or that L is a non-protein material associated with the S-protein molecule.

### *Inhibition of L-Antibody*

Solutions containing both L- and S-precipitable substances in high concentration showed no change in physical appearance when heated at 56°C for 1 hour. This led us to think that the L-antigen, which was no longer demonstrable by the usual precipitation technique, might still be present in these heated solutions in an altered form which was unable to precipitate with L-antibody. It seemed possible, furthermore, that such an altered antigen might inhibit L-antibody, and, indeed, this was found to be the case as shown by the following experiment.

*Experiment 1*—1500 cc of dermal filtrate were placed in cellophane tubes and concentrated to 100 cc by evaporation. The material was dialyzed against running water overnight, and while still in the original cellophane tube was again concentrated by evaporation to 50 cc. This solution reacted in a dilution of 1:1024 with optimal amounts of both L- and S-antibodies. Globulin material was obtained from the concentrate by fractional precipitation with ammonium sulfate. 50 cc of a solution of the reprecipitated globulin material were treated with 5 cc of standard citric acid-sodium phosphate buffer, pH 4.5. Most of the material insoluble under these conditions redissolved when taken up in 20 cc of diluted buffer solution, pH 6.6. This solution, containing globulin material insoluble at pH 4.5 and soluble at pH 6.6, had as much L- and S-activity as did the original concentrated dermal filtrate. After heating at 56°C for 1 hour the solution no longer precipitated with L-antiserum but its titer with S-antiserum was not reduced. One cc. of the heated solution was added to an equal amount of undiluted L-antiserum, the mixture was diluted with 4 cc of saline solution, incubated at 56°C for 1 hour, and stored at 3°C for 24 hours. No precipitate appeared. This treated mixture, which should have contained sufficient L-antibody to react strongly with unheated L-antigen, failed to form a precipitate when added to serial dilutions of unheated dermal filtrate and incubated under the usual conditions. The inhibition experiment was repeated with identical results when portions of the same solution of antigen which had been heated at 60°C, 80°C, and 90°C for 1 hour were used.

In the experiment just described L-antigen in the concentrated globulin material from dermal filtrate was affected in the usual manner by heating, *i.e.*, it no longer precipitated with L-antibody. A substance was present, however, in the heated solutions which was capable of inhibiting in some way the flocculation of L-antibody with unheated L-antigen. Since the partially purified material employed in the experiment was highly concentrated, it seemed desirable to repeat the inhibition procedure with a more dilute solution. For this purpose crude dermal filtrate prepared according to routine was used.

*Experiment 2*—Dermal filtrate, pool 6, which precipitated in a dilution of 1:128 in the presence of optimal amounts of either L- or S-antibody was heated in a closed flask in a water bath at 80°C. for 1 hour. The heated filtrate which no longer pre-

TABLE I  
*Inhibition of L-Antibody by Heated Dermal Filtrate*

Antigen	Treatment of L-antiserum 6314	Dilution of antigen					
		1:8	1:16	1:32	1:64	1:128	1:256
Dermal filtrate 6 (untreated)	Control	+++	++++	++++	+++	+	—
	1 volume heated vac- cina dermal filtrate 6	++	++++	+++	±	—	—
	3 volumes heated vac- cina dermal filtrate 6	—	—	±	—	—	—
	5 volumes heated vac- cina dermal filtrate 6	—	—	—	—	—	—
	5 volumes heated myx- oma dermal filtrate	++++	++++	++++	+++	±	—

\* Dilution of antiserum was 1:8 in each test.

cipitated with L-serum was added in varying amounts to 0.5 cc. portions of undiluted L-antiserum. Sufficient saline solution was added to each mixture to bring the final dilution of serum to 1:8 and the mixtures were incubated at 56°C. for 1 hour. Samples of the treated serum together with a control serum diluted only with saline, were tested for their capacity to precipitate with serial dilutions of unheated dermal filtrate, pool 6. The results summarized in Table I, show that the addition of an equal volume of heated filtrate to L-antiserum appreciably decreased the power of the serum to react with unheated filtrate. Furthermore, no precipitation occurred when the serum mixtures containing 3 and 5 volumes, respectively, of heat inactivated filtrate were tested against solutions known to possess active L-antigen.

The data obtained in Experiments 1 and 2 indicate that crude or partially purified solutions containing either small or large amounts of L- and S-substances lose their capacity to precipitate with L-antibody after heating, but are, nevertheless, still able to inhibit L-antibody.

Inhibition of antisoluble substance antibodies of vaccinia has been ob-

served by others. Craigie and Wishart (1) found that certain heated crude dermal filtrates employed for absorption studies with antivaccinal serum contained inhibiting substances which were carried along with the absorbed serum and subsequently interfered with the demonstration of residual antibodies. These authors regarded the inhibitory substances as non-specific in character and found that fractionation of the filtrates resulted in their elimination. Salaman (9) likewise observed reductions in precipitin and agglutinin titers following absorption of antiserum with large amounts of dermal filtrate; he regarded these effects as examples of the familiar inhibition which occurs in the presence of an excess of antigen and thought that they should not be called non-specific. Since the L-antigen had been rendered non-precipitable by heating, the inhibition of L-antibody observed in Experiments 1 and 2 was certainly not dependent upon the presence of an excess of precipitable L-antigen. Moreover, that the inhibition was serologically specific was demonstrated in the following manner:

*Experiment 3*—Dermal filtrate was prepared from rabbits cutaneously infected with the virus of myxomatosis by a technique essentially identical with that employed for rabbits infected with vaccinia. The filtrate which was rich in the A and B soluble antigens of myxoma was heated at 56°C for 1 hour and then mixed with antivaccinal serum. The mixtures were tested for L-precipitins of vaccinia in the usual manner. As indicated by the results summarized in Table I, no inhibition of L-antibody occurred even when 5 volumes of the myxomatous filtrate were added to the L-antiserum. It has already been recorded that vaccine dermal filtrate fails to inhibit the anti-soluble substance antibodies of myxomatosis (6).

Heated dermal filtrate appeared to be capable of specifically inhibiting L-antibody of vaccinia. It will be recalled that L-antisera are regularly prepared by absorbing hyperimmune antivaccinal serum with heated dermal filtrate; this absorption procedure when carried out under the proper conditions removes S-antibody and leaves L-antibody. This apparent contradiction was shown to depend on a quantitative factor, a much smaller amount of heated filtrate was generally needed to absorb S-antibody from immune serum than was necessary to obtain demonstrable inhibition of L-antibody.

*Experiment 4*—Unabsorbed hyperimmune serum, number 6814, reacted in a dilution of 1:32 with an optimal amount of unheated filtrate, pool 6, and in a dilution of 1:4 with heated filtrate. Complete removal of S-antibody without a detectable reduction in the quantity of L-antibody resulted when the hyperimmune serum was absorbed with an equal volume of a 1:8 dilution of dermal filtrate, pool 6, which had been heated at 80°C for 1 hour. L-precipitins, however, were no longer demonstrable in this antiserum after it was treated with an equal volume of four times concentrated solution of heated filtrate, pool 6. The filtrate had been concentrated by evaporation in a cellophane bag. Results of this experiment are summarized in Table II.

The material having the property of inhibiting L-antibody in the experiments so far presented always occurred in association with S-antigen. It seemed desirable, therefore, to prepare purified S-antigen by the method of Parker and Rivers (5) and to test the power of this substance to block or inhibit L-antibody.

*Experiment 5*—625 cc. of dermal filtrate, pool 7, having a titer of 1:128 with optimal dilutions of L- and S-antisera were boiled and subsequently the globulin fraction was salted out with ammonium sulfate. The redissolved globulin fraction was precipitated with alcohol, redissolved in water, precipitated at pH 4.6 with citric acid-disodium phosphate buffer solution, and, finally, redissolved in dilute citric acid-disodium phosphate buffer solution, pH 8.0. This solution was boiled, the pH was then changed to

TABLE II

*Preparation of L-Serum by Absorption of Immune Serum with Heated Dermal Filtrate and Inhibition of L-Antibody with the Same Material*

Hyperimmune serum 6814	Antigen: Dermal filtrate 6 diluted 1:16	Dilution of serum						
		1:2	1:4	1:8	1:16	1:32	1:64	1:128
Untreated	Unheated	++++	++++	++++	++++	++++	?	—
	Heated	++++	++	—	—	—	—	—
Absorbed*	Unheated	++++	++++	++++	++++	++++	?	—
	Heated	—	—	—	—	—	—	—
Inhibited†	Unheated	—	—	—	—	—	—	—

\* Absorbed serum was prepared by treating 1.5 cc. of serum 6814 with 1.5 cc. of a 1:8 dilution of heated dermal filtrate 6.

† Inhibited serum was prepared by treating 6814 with an equal volume of 4 × concentrated solution of heated dermal filtrate 6.

6.0 by the addition of sodium hydroxide, the solution was again boiled and then dialyzed free of salts. 0.25 cc. of a 1:1024 dilution of this final solution gave a precipitate with optimal amounts of S-antibody. A portion of the 41 cc. of final solution was dried from the frozen state and the residue was weighed, the solution before drying was shown to have contained 5.1 mg. of dry material per cc. Hence, on the basis of precipitin titer and dry weight, it was estimated that 1 part in 800,000 was sufficient to give a specific reaction with S-antiserum. The relative purity of the final preparation appeared to be of the same order as that obtained by Parker and Rivers. Portions of the final preparation of S-antigen as well as samples of different fractions obtained during the process of purification were tested in the usual way for their inhibitory effect on 0.5 cc. volumes of L-antiserum, number 6814. The results are summarized in Table III.

The results summarized in Table III show that the substance in crude vaccine dermal filtrate capable of inhibiting L-antibody was also present in materials



obtained at intermediate stages and in the final stage of the purification of S-antigen. These data indicate that L-inhibitor, like the precipitable form of L-antigen, is closely associated with S-antigen.

### *Inhibition of S-Antibody*

Earlier observations (10) indicated that S-antigen which has been heated with dilute alkali is not precipitated by its antibody. The capacity of such a degraded antigen to combine with S-antibody was investigated by means of the inhibition technique. The following protocol illustrates the results obtained in a typical experiment.

*Experiment 6*—40 mg of the final dried preparation of S-antigen from Experiment 5 were dissolved in 8 cc. of N/20 NaOH. The solution remained clear after heating

TABLE III  
*Inhibition of L-Antibody by a Preparation of S-Antigen*

Antigen	Fraction prepared from heated dermal filtrate	L-antiserum treated with fraction	Dilution of untreated dermal filtrate				
			1:8	1:16	1:32	1:64	1:128
Dermal filtrate		None	+++	++++	++++	++++	+
	Globulin fraction	1 volume	—	—	—	—	—
	Alcohol insoluble fraction of globulin	1 "	—	—	—	—	—
	Final solution of S-antigen	1 "	++	++	+	—	—
	" " "	2 volumes	—	±	—	—	—

Dilution of L-antiserum was 1:6 in all tests. Inhibited sera were obtained by adding 1 or 2 volumes of test material to 0.5 cc. amounts of L-antiserum. S-antigen titer of each test material was 1:1024. Final solution of S contained 5 mg per cc.

at 56°C for 90 minutes. A faint opalescence which appeared when the treated solution was brought to pH 7.2 with N/1 HCl was eliminated by ultracentrifugation at 30,000 R.P.M., the small amount of sediment thus obtained was discarded. Serial dilutions of the clear supernatant fluid which contained practically all of the degraded S-antigen did not form precipitates when incubated with optimal amounts of S-antibody. Varying quantities of the undiluted solution of treated antigen were mixed with 0.4 cc. volumes of S-antiserum, number 274, and with 0.3 cc. volumes of L-antiserum, number 6814, sufficient saline solution was added to each mixture to bring the final concentrations of antisera to their optimal dilutions. The mixtures, all of which remained clear after incubation at 56°C for 1 hour, were tested for demonstrable precipitins against L- and S-antigens by the usual methods. The results are summarized in Table IV.

The data presented in Table IV indicate that S-antigen of vaccinia which has been degraded by heat and alkali to a stage where it no longer precipitates with

its antibody is still able to combine with this antibody. For example, 0.5 mg of treated antigen completely inhibited the antibody in 0.4 cc. of undiluted S-antiserum. It is also evident that this preparation of degraded antigen had only a slight capacity to inhibit L-antibody. That the property of the degraded S-antigen to inhibit L-antibody was indeed less than that of the purified precipitable S-antigen from which it was derived may be seen by comparing the data given in the protocols of Experiments 5 and 6, for instance, 2 to 3 times as much of the alkali treated material was needed to produce the slight inhibitory effect on L-antibody observed in Experiment 5 where undegraded S-antigen was used.

TABLE IV  
*Inhibition of S-Antibody*

Antigen	Antiserum	Treatment of antiserum with degraded S	Dilution of antigen				
			1:8	1:16	1:32	1:64	1:128
Dermal filtrate	S (diluted 1:4)	mg					
		None	+++	++++	++++	++++	++
		0.125	+++	++++	++++	++++	++
		0.25	?	+++	++++	+	-
		0.50	-	-	-	-	-
		0.75	-	-	-	-	-
		1.00	-	-	-	-	-
	L (diluted 1:6)	None	+++	++++	++++	++++	++
		1.00	++++	++++	++++	+++	+
		7.50	+++	++	++	-	-

0.4 cc. volumes of S-antiserum and 0.3 cc. volumes of L-antiserum were treated with the designated amount of S-antigen which had been heated at 56 C for 90 minutes in the presence of N/20 NaOH.

Inhibition of S-antibody can also be demonstrated by adding the antibody directly to mixtures of native and degraded S-antigen. In this type of experiment, however, the latter material must be present in large amounts in comparison to the former. This is illustrated by the data presented in Table V which summarizes the results obtained when alkali and heat treated S-antigen from Experiment 6 was added in increasing amounts to 0.4 cc. volumes of unheated dermal filtrate, after which serial dilutions of the mixtures were prepared and incubated with optimal amounts of L- or S-antibody. Results of the titrations made with the mixture containing 0.1 mg of degraded S-antigen were comparable to the controls. The presence of 1.0 mg of the non-precipitable or degraded antigen prevented flocculation of the native S-antigen only in the lowest dilutions of the titrations with S-antibody, while 5.0 mg completely blocked precipitation of native S-antigen with its antibody through

out the range of dilutions. In none of the mixtures was the reaction with L-antibody appreciably altered.

On several occasions S-inhibitor has been encountered in preparations of vaccine dermal filtrate that were not subjected to alkaline treatment. In these experiments the filtrates were concentrated 10 to 20 times before boiling. The technique for purifying S-antigen was originally applied to crude dermal filtrates (5). In order to avoid working with large volumes, we first concentrated the crude filtrates by evaporation in cellophane tubes. The results obtained when the purification procedure was applied to these concentrates were disappointing in that yield of S-antigen was negligible as determined by pre-

TABLE V  
*Inhibition of S-Antibody—Continued*

Antigen mixture		Antiserum	Dilution of original dermal filtrate			
Dermal filtrate	Degraded S-antigen		1:8	1:16	1:32	1:64
cc	mg					
0.4	0.1	L	++++	++++	++++	++
		S	++++	++++	++++	++++
0.4	1.0	L	++++	++++	+++	++
		S	—	++++	++++	++++
0.4	2.0	L	++++	++++	+++	++
		S	—	—	—	++
0.4	5.0	L	++++	++++	+++	+
		S	—	—	—	—

Mixtures of dermal filtrate and degraded S-antigen were incubated at 37°C for ½ hour and then diluted serially. Constant amounts of L-antiserum 6814 diluted 1:6 and of S-antiserum 274 diluted 1:4 were added and the titration results were read after incubation overnight at 50°C.

cipitin tests. The failure to demonstrate the expected amounts of S-antigen in the solutions was found to be dependent upon the presence of an inhibitor which could be removed, leaving behind precipitable S-antigen. The results of this type of work are illustrated by the following experiment.

*Experiment 7*—960 cc. of dermal filtrate, pool 8, were dialyzed in cellophane tubes against running water and then concentrated to 90 cc. in the same tubes by evaporation in a stream of air. The clear solution became opalescent after gentle boiling for 5 minutes, and the small amount of precipitate that formed was removed by centrifugation. The globulin fraction obtained by precipitation with ammonium sulfate was redissolved in water, dialyzed free of sulfate ions, and brought back to a volume of 90 cc. The original crude dermal filtrate in a dilution of 1:64 precipitated with L- and S-antisera, but the concentrated solution of heated globulin gave only a slight precipitate in dilutions of 1:8 to 1:32 with S-antiserum. A portion of the solution

of globulin was fractionated by the method of Craigie and Wishart (1) for the concentration of LS-antigen. Only about half of the voluminous white precipitate obtained at pH 4.5 redissolved when it was suspended in buffer solution, pH 6.6. The solution containing the material which dissolved at pH 6.6 had a precipitin titer of 1:128 when tested with S-antiserum. The material which failed to dissolve at pH 6.6 was soluble in dilute buffer solution, pH 9.0, and the solution remained clear when brought back to pH 7.0. While this solution did not precipitate in dilutions of 1:4 to 1:512 in the presence of an optimal amount of S-antibody, it was found to have a marked inhibiting effect on S-antibody. S-antiserum treated with 3 volumes of the solution would not precipitate with native S-antigen. On the other hand, L-antiserum was not appreciably inhibited by 5 volumes of the solution.

The results obtained in Experiment 7 throw some light on the work of Craigie and Wishart (1). For example, it was shown that under certain conditions the heating of dermal filtrate, even in the pH range near neutral reactions, may result in the formation of S-inhibitor. Furthermore, it was found that S-inhibitor can be separated from precipitable S-antigen by means of the different solubilities of the two substances at several pH values.

#### DISCUSSION

The results of the foregoing experiments may be briefly summarized as follows. Dermal filtrate prepared from the skin of rabbits infected with the virus of vaccinia contains the heat labile (L) and heat-stable (S) antigens of vaccinia which can be demonstrated by the precipitation technique. Gentle heating destroys the precipitability of L-antigen but leaves in solution a substance capable of inhibiting L-antibody. This L-inhibitor, like precipitable L-antigen, is closely associated with S-antigen and cannot readily be separated from it. Preparations of S-antigen can also be degraded by any of several methods to a stage where precipitation with S-antibody does not occur, however, inhibition of S-antibody with this material is easily demonstrated. Degraded S-antigen, in contrast to precipitable S-antigen, has little power to inhibit L-antibody. The solubilities of S-inhibitor are different from those of S-antigen and L-inhibitor.

The immediate objective of the present experiments, *viz.*, the demonstration of degraded forms of L- and S-antigens of vaccinia which are capable of inhibiting their specific antibodies, was accomplished. The studies were less successful, however, in regard to their ultimate objective which was the elucidation of the relationship between L- and S-antigens. Nevertheless, the observations just reported may serve as the basis for several hypotheses on the relationship of these two serologically active substances.

One of the simplest of the hypotheses is as follows. The native antigen present in infected tissue is L, or the antecedent substance from which it is derived. L is readily degraded during manipulation and storage to a slightly modified

material, S, which is still capable of eliciting a specific antibody in animals and which combines with L-antibody as demonstrated by inhibition tests S-antigen can be further degraded to a stage where it inhibits but fails to precipitate with its antibody, and, in this form it loses most of its ability to combine with L-antibody. A graphic representation of the various stages of degradation according to this scheme is presented in Text-fig 1. There are

Hypothesis	Native materials in dermal filtrate	Effect of heat	Effect of heat and alkali
I	L Precipitates with L-antibody	S Inhibits L-antibody Precipitates with S-antibody	S' No inhibition of L-antibody No precipitation with S antibody Inhibits S-antibody
II	L Precipitates with L-antibody  S Precipitates with S-antibody	L' Inhibits L-antibody  S Precipitates with S-antibody	L* No inhibition of L-antibody  S' Inhibits S-antibody
III	(L — S) Precipitates with L-antibody Precipitates with S antibody	(L' — S) Inhibits L-antibody Precipitates with S antibody	(L* — S') No inhibition of L-antibody No precipitation with S antibody Inhibition of S-antibody
	Other theoretical combinations		
	(a) (L — S') Precipitates with neither antibody Inhibits both antibodies	(b) (L' — S') Neither precipi- tates nor inhibits	(c) (L — S) Precipitates with L-antibody No precipitation with S antibody Inhibits S-antibody

TEXT-FIG 1

several serious objections to this hypothesis. No reasonable explanation is at hand for the regular occurrence of equal amounts of L- and S-antigen in preparations from infected tissue. Moreover, it should be possible, if the hypothesis were correct, to demonstrate a simultaneous increase in S along with a decrease in L during the various procedures which render L-antigen non-precipitable.

A second hypothesis might begin with the assumption that L- and S-antigens are separate protein molecules which are distinguishable by serological means but not by ordinary physical and chemical procedures. According to this idea each of the antigens could be degraded independently, but, since L is more

easily affected than S, the labile antigen would generally be denatured one step further than the stable one (Text fig 1). The similar physicochemical nature of the native substances might also be considered to be characteristic of the mildly degraded antigens, thus, a separation of L-inhibitor and S-antigen would be difficult. This hypothesis, like the first, affords no explanation for the uniform ratio of L- and S-antigens in crude filtrates. Furthermore, it is hard to reconcile it with the almost invariable results obtained in absorption experiments, namely, the removal of both antigens on the addition of either antibody.

A third hypothesis deals with an LS-complex similar to that postulated by Craigie and Wishart (1). No assumptions need be made about the chemical nature of the L-part of this complex or about the type of union between it and the protein like S-part. As in the second hypothesis, the L-reacting substance would be considered to be degraded more readily than the S under ordinary conditions, and complexes might be formed of L'S and L''S' on treatment with heat or heat and alkali, respectively (Text fig 1). In such a scheme the first degradation product, e.g., L' would inhibit L-antibody but not be precipitated by it, while L'' would have lost most of its capacity to inhibit L-antibody. Similarly, stages in the degradation of the S-portion of the complex could be postulated. Additional complexes with various combinations of native and degraded stages of the L- and S-parts might be considered, several of these are represented in Text fig 1, (a), (b), (c). The objections raised to the first two hypotheses are not valid for the last one. The unusual results of occasional absorption experiments reported by Parker (2) and Craigie and Wishart (3) can be explained by this hypothesis if one assumes that under certain rare conditions a portion of the LS-complex in dermal filtrate is degraded to a form represented as LS' (Text fig 1, (c)). A mixture of this complex and native LS when treated with S-antibody could result in the precipitation of LS, leaving in solution LS' combined with S-antibody. Such a soluble antigen-antibody combination might then be precipitated on the addition of L-antibody.

At the time these experiments were completed we were inclined to accept the third hypothesis as the one which more nearly explained the available data on the relationship of the L- and S-antigens of vaccinia. Work reported in accompanying and subsequent papers (4, 11) has done much to strengthen our belief that this hypothesis is substantially correct.

#### CONCLUSION

Experimental data are presented which may be interpreted as follows. The heat labile (L) and heat-stable (S) antigens of vaccinia occur in nature as a complex consisting of a single substance with two serologically active parts, each of which may be degraded independently of the other.

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## BIBLIOGRAPHY

- 1 Craigie, J , and Wishart, F O , *J Exp Med* , 1936, 64, 819
- 2 Parker, R F , *J Exp Med* , 1938, 67, 361
- 3 Craigie, J , and Wishart, F O , *J Bact* , 1938, 39, 25
- 4 Smadel, J E , Shedlovsky, T , Rothen, A , and Hoagland, C L , to be published
- 5 Parker, R. F , and Rivers, T M , *J Exp Med* , 1937, 65, 243
- 6 Smadel, J E , Ward, S M , and Rivers, T M , *J Exp Med* , 1940, 72, 129
- 7 Smith, W , *Brit J Exp Path* , 1932, 13, 434
- 8 Ch'en, W K , *Proc Soc Exp Biol and Med* , 1934, 32, 491
- 9 Salaman, M H , *Brit J Exp Path* , 1937, 18, 245
- 10 Smadel, J E , Lavin, G I , and Dubos, R J , *J Exp Med* , 1940, 71, 373
- 11 Shedlovsky, T , and Smadel, J E , *J Exp Med* , 1942, 75, 165

## THE LS-ANTIGEN OF VACCINIA

### II ISOLATION OF A SINGLE SUBSTANCE CONTAINING BOTH L- AND S-ACTIVITY

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The intimate association of the heat labile (L) and heat-stable (S) soluble antigens of vaccinia was shown by the work of Craigie and Wishart (1). Moreover, observations on the degraded forms of these antigens, reported in the previous paper (2), further indicated the close relationship of these two antigens. The fact that the L-antigen is readily denatured by a number of procedures which are ordinarily used for purification of immunologically active substances has delayed the acquisition of knowledge concerning its nature. On the other hand, the heat stable antigen has been studied in considerable detail (3, 4) and has been shown to be a protein substance. Although the results of several experiments (4, 5) have been interpreted as indicating that L-antigen may be obtained free of the S-antigen, these experiments are also subject to a different interpretation (2). The work reported here was undertaken in the hope of obtaining pure L-antigen in sufficient amounts to study its physical and immunochemical properties. As will be shown, the L-antigen is not found free from the S-reacting substance under ordinary conditions. Indeed, the results indicate that the L- and S-immunological activities reside in a single native protein molecule. A method for isolating pure LS-antigen of vaccinia from virus-free filtrates of infected rabbit skin will be given in this communication together with observations on the physical and immunological properties of the native substance and of some of its degraded forms.

#### *Materials and Methods*

*Vaccine Dermal Filtrate*—Dermal filtrate was available in large quantities as a by-product obtained from the preparation of washed elementary bodies of vaccinia which were used for other studies. The technique of Craigie (6) was employed without significant modification. Dermal pulp from each cutaneously infected rabbit was suspended in 30 cc. of a 1:50 dilution of standard phosphate buffer solution pH 7.2 and the solution which remained after removal of tissue particles and elementary bodies by means of differential centrifugation was filtered immediately through a Seitz pad. Bacteriologically sterile virus-free filtrates were stored at 3°C. until 800 to 1200 cc. had been accumulated usually a period of a month.



*Antiserum.*—L-antiserum used throughout this portion of the work was prepared from pooled sera obtained by bleeding vaccine virus immune rabbits which had been hyperimmunized with washed active elementary bodies of vaccinia, the serum was absorbed free of S-antibody with heated crude dermal filtrate. S-antisera were obtained from rabbits which had been immunized with a non-infectious solution of purified S-antigen (4). Precautions were taken to prevent these non immune animals from becoming accidentally infected with vaccinia during the period of immunization. Our experience, like that of Parker, indicated that solutions of S antigen prepared in this manner elicit a poor antibody response in rabbits and in order to obtain potent sera several courses of treatment were given. For the final course of immunization, washed and graded collodion particles were added to the solution of S-antigen and the mixture was injected intravenously.

*Serological Methods.*—The serological techniques employed in this work have been reviewed in a previous paper (2).

*Electrophoretic Technique.*—Electrophoretic experiments were carried out in the Tiselius apparatus with the schlieren-scanning optical system (7) the details of which have been discussed elsewhere. The temperature of the thermostat containing the cell was regulated at 1°C, but all the values of mobility given in this paper have been corrected to 0°C.

## EXPERIMENTAL

*Observations on Concentrated Whole Dermal Filtrate.*—The results obtained in studies in which the electrophoretic technique was applied to concentrated dermal filtrate, both before and after heating, are illustrated in the following experiments.

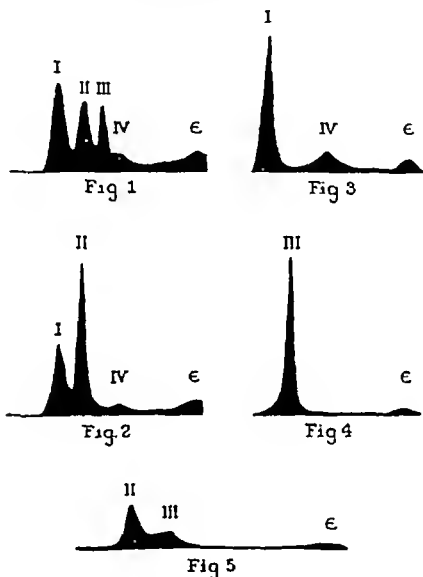
*Experiment 1.*—One liter of dermal filtrate was concentrated to a volume of 100 cc by means of evaporation through a cellophane sausage casing placed in an air stream at room temperature for 24 hours. The L- and S-titers of this concentrate were 1:1000. A portion of the material was dialyzed against 0.05 M lithium-veronal buffer solution at pH 7.9<sup>1</sup>. Upon electrophoresis this dialyzed material was found to display four boundaries, all of which corresponded to negatively charged substances at this value of pH. A reproduction of the electrophoretic pattern obtained is shown in Fig. 1. The mobilities of the four components, which were designated I to IV, were  $6.7 \times 10^{-5}$ ,  $5.4 \times 10^{-5}$ ,  $4.4 \times 10^{-5}$ , and  $3.4 \times 10^{-5}$  cm/sec per volt/cm, respectively. In Fig. 1, as in subsequent figures, the first peak on the right,  $\epsilon$ , does not correspond to any component, but is due to a gradient of buffer salts.

*Experiment 2.*—A portion of the same material was heated at 70°C for 1½ hour in a closed vessel (a procedure which inactivates L without destroying S) and an electro

<sup>1</sup> This solution contained diethylbarbituric acid, its lithium salt, and lithium chloride, each at 0.025 M. The chloride was used to build up the ionic strength, since the diethylbarbituric acid concentration is fixed by its relatively low solubility at 0°C.

phoretic determination was made under conditions identical with those described above. The electrophoretic pattern obtained in this experiment is illustrated in Fig 2.

It is immediately obvious from Figs 1 and 2, that the results obtained in the two experiments were strikingly different. As a result of heating, one component (III) had completely disappeared and another component (II) had been



increased in amount, on the other hand, components I and IV were unaffected by heating under these conditions. A quantitative estimation of the relative amounts of components II and III in these two preparations was obtained from the measurement of the areas in the electrophoretic patterns. This indicated that the increase in component II which occurred on heating was approximately equal to the loss of component III.

When the observations described above were first made we were not certain whether L- and S-activities were associated with one or with two substances

Therefore, we were inclined to believe from these data that component corresponded to L-antigen and that component II corresponded to S-antigen; furthermore, that as a result of heating, L had been transformed to S. It can be said at once that this hypothesis was subsequently proved wrong. Nevertheless, we immediately attempted to isolate by electrophoretic separation four components shown in Fig 1, in order to identify the substances serologically. These results may be briefly summarized as follows: components I, fastest, and IV, the slowest, were readily isolated and were found to be serologically inert. Sharp electrophoretic separation of components II and III was not possible, due to the fact that their respective mobilities were not sufficiently different for such resolution. Even when electrophoresis was carried out in solutions with pH values from 6.0 to 8.6, such fractions which were obtained invariably showed L- and S-activity in equal amounts. Since the above methods were inadequate for the purpose, fractionation of the L- and S-antigens from crude dermal filtrate was attempted by other means.

*Fractionation of Dermal Filtrate by Precipitation*—It has been shown by Craigie and Wishart (1) that the L- and S-antigens can be concentrated from crude dermal filtrate by precipitating at pH 4.5 and redissolving the precipitate at pH 6.5. This procedure enabled these workers to eliminate a considerable amount of serologically inert nitrogenous material, present in the crude filtrate, without appreciably reducing the titer of the antigens in the final preparation. Parker and Rivers (3), in their experiments dealing with the purification of S-antigen from heated dermal filtrate, had also observed that the heat-stable active substance has similar solubility characteristics. Procedures based on these observations were employed in the fractionation of concentrated dermal filtrate and the fractions thus obtained were studied electrophoretically and serologically. The following experiment illustrates the methods employed and the results obtained.

*Experiment 3*—1150 cc. of vaccine dermal filtrate, collected over a period of 5 weeks, were concentrated by evaporation from cellophane bags to a volume of 110 cc. A slight amount of insoluble material present in the concentrate was removed by centrifugation and discarded. The clear concentrate was again placed in a cellophane sack and dialyzed overnight against 4 liters of unbuffered physiological saline solution at 3°C. The sack and its contents were then suspended in 450 cc. of 0.05 M acetate buffer solution at pH 4.63, also at 3°C. Precipitation began at once at the surface of the cellophane membrane. The sack was agitated from time to time and by the end of 3 hours no further increase in the precipitate could be noted. The material was then removed from the sack and the precipitate was separated by centrifugation in the cold. The clear, straw-colored supernatant fluid, which had a pH of approximately 4.6, was set aside for further study; this was designated fraction A. The coarser sediment, which occupied a volume of about 2 cc. in the centrifuge tube, was washed in the cold with 45 cc. of the same acetate buffer solution. The reser-

mented, washed material was then taken up in 50 cc. of 0.05 M cacodylate buffer solution at pH 6.31 and dialyzed overnight against 450 cc. of the same solution at 3°C. Approximately half of the material dissolved under these conditions. The material insoluble at pH 6.31 and the substance dissolved at this pH were separated by centrifugation. The clear, pale straw-colored supernatant solution was labeled fraction B and stored. The sediment was washed with the cacodylate buffer solution and then suspended in 50 cc. 0.05 M veronal buffer solution of pH 8.56. Following dialysis against a large volume of the same buffer solution an appreciable part, but not all of the material dissolved. The clear liquid was again separated from the precipitate by centrifugation and designated fraction C. The precipitate which was insoluble at pH 8.56 dissolved partially in 0.1 M borate buffer solution pH 11.0 and almost completely in 0.05 M NaOH, since all the material in dermal filtrate was originally soluble in neutral solutions; this portion probably consisted largely of denatured products.

The three fractions which had been saved for further study were: A, the material which remained soluble at pH 4.63; B, the material which was insoluble at pH 4.63 but soluble at pH 6.31; and C, the material which was insoluble at pH 4.63 and 6.31, but soluble at pH 8.56. Portions of fractions A and B were placed in cellophane sacks and dialyzed against 0.05 M lithium veronal buffer solution at pH 7.91 for 1 or 2 days in the cold, after which they were examined by electrophoresis; similar data were obtained on fraction C in veronal buffer solution pH 8.56. The serological properties of all three fractions were investigated.

Fraction A was found to contain only two components, these had the same electrophoretic mobilities as components I and IV in whole dermal filtrate. Fraction B consisted of a single substance which was electrically homogeneous and which moved at a rate corresponding to that of component III. Fraction C contained a trace of component III, but most of the material appeared to correspond to component II in whole filtrate. The electrophoretic patterns obtained with fractions A, B, and C are shown in Figs. 3, 4, and 5, respectively.

The results of serological studies on the original material and on fractions A, B, and C are summarized in Table I. Briefly it may be stated that fraction B, consisting of the electrically homogeneous component III, contained practically all of the L- and S-reacting material present in the original concentrated dermal filtrate. It gave a precipitate when diluted 1:1600 and incubated in the presence of an optimum amount of L- or of S-antibody. The small amount of L- and S-precipitinogen activity found in the C fraction was completely lost after refractionation, furthermore, all of the serologically active material was now recovered in the solution corresponding to the original B fraction. The A fraction was serologically inert.<sup>2</sup>

This portion of the work may be summarized as follows. Components I and

<sup>2</sup> In several early experiments in which dialysis of crude filtrate against pH 4.6 buffer solution was inadequate appreciable amounts of components II and III were left in fraction A.

IV found in vaccine dermal filtrate may be separated quantitatively from components II and III by precipitation of the latter at pH 4.6. Furthermore, component III can be isolated from this precipitate in uncontaminated form by extracting this precipitate at pH 6.3. Such a solution of component III contains practically all of the L- and S-reactive substance present in the original filtrate.

*Observations Indicating that a Single Substance in Its Native State Contains Both L- and S-Activity*—In our laboratory, precipitation titrations with the

TABLE I  
*Serological Activity of Fractions Derived from Vaccine Dermal Filtrate*

Test solution	Anti serum	Dilution of test solution							
		1:25	1:50	1:100	1:200	1:400	1:800	1:1600	1:3200
Concentrated dermal filtrate	L		++++	++++	++++	++++	++++	++	+
	S		±	+++	++++	++++	++++	++++	+
Fraction A	L	—	—	—	—	—			
	S	—	—	—	—	—			
Fraction B	L		++++	++++	++++	++++	+++	++	±
	S		±	++++	++++	++++	++++	++	±
Fraction C	L	++++	++++	+++	+	±			
	S	++++	++++	+++	++	+			
Refractonated C	L	±	—	—	—	—			
	S	+	±	—	—	—			

L-antiserum 1601 was used in a dilution of 1:2 throughout. S-antiserum 493 was used in a dilution of 1:8. 0.01 M lithium-veronal buffer solution, pH 8.6, containing 0.9 per cent of NaCl served as diluent. Test mixtures were incubated at 50°C overnight.

See text for preparation of test materials

soluble antigens of vaccinia are ordinarily carried out by incubating the antigen-antibody mixtures at 50°C for 18 hours in closed tubes. Such an incubation period is sufficient to degrade the heat-labile antigen, L, to a state where it no longer precipitates with its antibody. Consequently, at this stage in the experiments it was necessary to consider the possibility that the material designated as component III was a substance which possessed only L-activity in its native form. According to such an hypothesis, this native material could be degraded by heating to a substance with the electrical mobility of component II and with S-activity.

In order to test this hypothesis a solution containing component III was diluted serially in the usual manner, and portions of each dilution were placed in tubes with

optimal amounts of L- or of S-antibody. Four sets of duplicate titrations were thus made and each set was incubated for 18 hours at a different temperature namely, at 3°, 20°, 37°, and 50°C.

In each set of titrations the precipitin endpoint in the presence of S-antibody was identical with that obtained in the presence of L-antibody. Flocculation was slower at the lower temperatures, and with incubation at 3 C. periods of 48 to 72 hours were necessary in order to develop maximum precipitation. end-points thus obtained equalled those observed after 18 hours at 50°C.

The presence of an S-reactive substance in solutions of component III which were incubated at temperatures that do not change the precipitability of the heat labile substance, clearly shows that component III in its native state possesses both L- and S-reacting portions, therefore, S cannot be a degradation product of L-antigen. Observations reported in succeeding sections will clarify the relationship between component II and heated component III.

Evidence based on absorption experiments in which solutions of component III were used with L- and with S-antisera indicates that the two antigenic parts of component III cannot be separated by this method. The following protocol illustrates the results obtained with one of several preparations of antigen absorbed with antisera.

*Experiment 4*—40 cc. of an electrophoretically homogeneous solution of component III were obtained from 800 cc. of vaccine dermal filtrate by the method described in the protocol of Experiment 3. The solution had a titer of 1:2048 with L- and with S-antibody. A 0.7 cc. volume of S-antiserum 493 was mixed with 0.1 cc. of the solution of antigen in one instance, and in another with 0.05 cc. of antigen and 0.05 cc. of saline. Each antigen antibody mixture was diluted with an equal volume of saline solution, and incubated at 37°C for 4 hours and then at room temperature for a similar period of time. The voluminous precipitate which formed was removed by centrifugation. Similar absorptions were carried out with 0.8 cc. volumes of L-antiserum 1601 and varying amounts (0.01 to 0.10 cc.) of solution of antigen, sufficient saline solution being added to each mixture to bring the final volume to 1.6 cc. These were tested for residual antigen and for residual antibody. The results of these tests which are summarized in Table II show that absorption with either L- or S-antibody removes both L- and S-antigenic substances completely or reduces both to the same degree.

It is apparent from these observations that the electrically homogeneous<sup>3</sup> component III, which was obtained from the dermal filtrate, contains both L- and S-activity and that the two serologically distinct parts are inseparable in the native substance. Ultracentrifugal and chemical studies on this material, which will be reported in another paper, showed it to be a homogeneous protein.

<sup>3</sup> Studies on the material at values of pH between 6.2 and 8.6 consistently revealed but one electrophoretic component. These measurements are discussed in detail in a subsequent paper.

TABLE II  
Absorption of Solutions of Component III with L- and S Antibody

Absorption mixtures		Residual antigen										Residual antibody				
Antigen	Antiserum type	Anti sera	Dilution of original antigen solution										Dilution of absorbed mixture			
cc	cc		1 16	1 32	1 64	1 128	1 256	1 512	1 1024	1 2048	1 4096	1 1	1 2	1 4	1 8	
	Unabsorbed	L S	+++ —	+++ —	+++ ±	+++ +	+++ +	+++ +	+++ +	+++ +	— —	—	—	—	—	
0 01	Anti S 0 7	L S	— —	— —	— —	— —	— —	— —	— —	— —	— —	—	—	—	—	
0 05	Anti S 0 7	L S	— —	— —	— —	— —	— —	— —	— —	— —	— —	—	—	—	—	
0 1	Anti L 0 8	L S	+++ +++	+++ +++	+++ +++	+++ +++	+++ ++	± ±	± ±	— —	— —	—	—	—	—	
0 05	Anti L 0 8	L S	+++ +++	+++ +++	± ±	— —	— —	— —	— —	— —	— —	—	—	—	—	
0 025	Anti L 0 8	L S	— —	— —	— —	— —	— —	— —	— —	— —	— —	++	—	—	—	

L-antiserum 1601 was prepared from pooled sera of rabbits hyperimmunized with active elementary bodies of vaccinia by absorption of S-antibody with heated dermal filtrate. S-antiserum 493 was obtained from a rabbit immunized with a non infectious fraction of heated dermal filtrate rich in the heat stable soluble antigen of vaccinia. Tests for residual antigen were carried out with optimal dilutions of antisera, i.e., 1 2 for L- and 1 8 for S-antisera. Determinations of residual antibody were made by adding 0.25 cc of a 1 16 dilution of unheated vaccine dermal filtrate to equal volumes of serial dilutions of the absorbed mixture.

See text for details of absorption technique

with a molecular weight near that of serum globulins. On the basis of electrophoresis and ultracentrifugal evidence, therefore, we conclude that component III is a single molecular substance containing both L- and S-activity. Henceforth we shall designate it as LS-antigen. This LS-antigen is probably the substance that Craigie and Wishart (1) prepared from the same type of source material and called "LS fraction." Our method of isolation of the antigen is similar to theirs and the serological data obtained following incubation at various temperatures and by absorption with L- and S-antibody agree with their findings. The present experiments supplement the observations of these authors in that they were done with solutions of antigen which were proved to be pure by a number of different criteria and hence these experiments carry additional weight in theoretical discussions of the nature of LS-antigen.

*Effect of Heat on LS Antigen*—Destruction of the precipitability of the labile soluble substance of vaccinia by heating has been well established (1, 5). The combination between heated L-antigen and L-antibody without subsequent flocculation has been discussed in the preceding paper (2). Since pure LS-antigen was now available it seemed desirable to study the effect of heat on its physical and serological characteristics.

*Experiment 5*—The observations described in the following experiment are typical of those noted in the study of several different preparations of LS-antigen. A portion of the solution of LS-antigen from Experiment 4 was heated for  $\frac{1}{2}$  hour in a water bath at  $70^{\circ}\text{C}$ . in a closed tube. The solution which had been clear now showed a faint opacity. After removing the trace of insoluble material by high speed centrifugation (12,000 R.P.M.) the solution was redialyzed against 0.05 M lithium veronal buffer solution at pH 7.91 and was examined by electrophoresis.

The electrophoretic mobility of this lot of unheated LS-antigen under these conditions was  $4.0 \times 10^{-5}$  cm./sec. per volt/cm. After heating this solution, a single electrically homogeneous component was still present, but it now moved at a rate of  $5.9 \times 10^{-5}$  cm./sec. per volt/cm. This preparation of heated LS was inhomogeneous when examined in the analytical centrifuge as will be shown in another paper in this series. The precipitin titer of the solution of unheated LS was 1:2048 with both L- and S-antibody; the heated LS still titrated 1:2048 with S-antibody but failed to precipitate over the range of dilutions from 1:8 to 1:4096 in the presence of L-antibody.

This experiment throws considerable light on the early observations which misled us into believing that components II and III represented S- and L-antigens respectively. Heating destroyed the precipitability of the L-part of the LS-antigen and increased the mobility of the degraded molecule to a value almost identical with that of component II in crude dermal filtrate. The augmentation of component II concurrent with the disappearance of component III in heated crude filtrate thus appears to have been a coincidence.



*The Occasional Occurrence of Partially Degraded LS-Antigen in Crude Dermal Filtrate*—Although pure LS-antigen had been previously obtained in four successive experiments by means of the fractionation technique which has been described, it was found in one experiment that the fraction which usually contained only LS-antigen was contaminated with a component having the mobility of either component II or of heated LS-antigen

*Experiment 6*—850 cc of dermal filtrate were concentrated and fractionated in the manner described in Experiment 3. Fraction B was examined by electrophoresis in 0.05 M lithium-veronal buffer pH 7.89 and found to contain two components, one component corresponding to LS-antigen was present in an appreciable amount, and the other, corresponding to either heated LS-antigen or component II, was estimated to be present in about  $\frac{1}{2}$  the concentration of LS-antigen. Although the titer of the solution was 1:1600 with L-antibody and 1:3200 with S-antibody this was considered inconsequential at the time. Accordingly, the solution was refractionated to remove the contaminating material. In short, the material was precipitated three times at pH 4.6 and each time the precipitate redissolved almost completely at pH 6.6. The final preparation gave essentially the same electrophoretic pattern and serological titers as did the original fraction B.

Refractionation of the solution which might have been expected to eliminate the contaminating material if it were component II failed to accomplish this. Furthermore, since the contaminant had solubility characteristics similar to those of LS-antigen it appeared likely that it was a degraded form of LS-antigen. Therefore, at this point, it seemed desirable to know whether the technique of fractionation, as regularly employed, was adequate to separate heat-degraded LS-antigen from native LS-antigen.

*Experiment 6 (Continued)*—14 cc of the three times fractionated solution B from Experiment 6 were still available. The solution had an S-titer of 1:1600 and L-titer of 1:800. One half of the material was heated at 70°C for  $\frac{1}{2}$  hour. This portion then failed to react with L-antibody but still retained its S titer of 1:1600. The two solutions were recombined, the precipitin titers were then 1:400 for L-antigen and 1:1600 for S-antigen, as might have been expected.

After dialysis, the mixture was again studied electrophoretically, the pattern revealed the presence of two components with mobilities corresponding to LS-antigen and heated LS-antigen, which were present in concentrations closely corresponding to their respective titers. The material was then subjected to the solubility fractionation process and was again examined electrophoretically. No change in the resulting pattern was noted. The serological titers remained the same.

Essentially similar electrophoretic and serological observations were made on a mixture containing equal amounts of solutions of unheated and heated LS antigen from Experiment 3. In this case, however, the two electrical components were about equal quantitatively, and the solution had titers of 1:800 to 1:1600 with L- and S-antibody respectively.

The results obtained in Experiment 6 indicate that heat-degraded LS-antigen has essentially the same solubility characteristic as native LS-antigen and hence cannot be separated from it by the procedures employed. This is of importance for it indicates that, in general, dermal filtrate contains no partially degraded LS-substance, *i.e.*, one possessing S-activity but not L-activity. In other words, all of the L- and S-activity in fresh dermal filtrate is carried by component III. In the single experiment in which pure LS-antigen was not isolated by the process of fractionation it appears that the contaminant was a degraded form of antigen similar to heated LS-antigen. The reason for the appearance of this contaminant in a single pool of dermal filtrate is not at hand. It may be pointed out, however, that, unlike the usual preparations, in this case, several of the lots of the angle supernatant fluid from the suspension of crude pulp had not been filtered immediately, but were allowed to stand at ice box temperature for several days before being passed through a Seitz pad. The centrifuged but unfiltered fluid is slightly opalescent and contains some virus, tissue debris and bacteria, and the presence of one or more of these might well have contributed to partial denaturation of LS-antigen by enzymatic digestion or otherwise.

*Inhibition of L- and S Antibodies by Degraded Forms of LS Antigen*—The interpretation of the experiments described in the previous paper (those dealing with inhibition of anti-soluble-substance antibodies of vaccinia by various preparations of materials from vaccine dermal filtrate) was difficult, due to the lack of critical evidence showing that the degradation products of a single substance were capable of inhibiting the two antibodies. Accordingly, solutions of pure LS-antigen were treated with heat alone, and also with heat and dilute alkali, and the specific inhibitory properties of the resulting preparations were studied (Experiments 7 and 8).

*Experiment 7*—A portion of solution obtained from Experiment 3 was heated at 70°C. for  $\frac{1}{2}$  hour. The resulting solution still precipitated in a dilution of 1:1600 with optimal amounts of S-antibody, but failed to flocculate when dilutions of 1:25 to 1:3200 of the solution were mixed with optimal amounts of L-antibody. Inhibition tests were made in the following manner. Varying amounts of two different L-antisera were treated with varying amounts of heated LS-antigen solution. Sufficient saline solution was added to the test mixtures to make the final dilutions of serum comparable. The mixtures were incubated at 50°C. for  $\frac{1}{2}$  hour and then at 37°C. for an additional  $\frac{1}{2}$  hour. The solutions remained clear and centrifugation failed to sediment an appreciable amount of material. The test sera, together with controls, prepared by properly diluting antisera with saline and incubating for a similar period, were then set up in constant amounts with serial twofold dilutions of unheated crude dermal filtrate. Illustrative data obtained are summarized in Table III.

It is evident from the results summarized in Table III that a solution of LS-antigen, shown to be pure by electrophoresis and ultracentrifugation, when

degraded by heat to the stage where it fails to give a precipitin reaction with L-antibody, is still capable of combining with L-antibody as demonstrated by the inhibition technique. An additional point of interest may be mentioned regarding the serological behavior of LS-antigen degraded by heat. Mixtures of serial dilutions of such antigen and optimal amounts of L-antibody, which give no precipitate after incubation, were subsequently treated with optimal amounts of S-antibody and incubated in the usual manner. The precipitin titers in these instances were approximately the same as those obtained in control titrations in which no L-antibody was employed. Apparently, the presence of L-antibody, which was presumably combined with the degraded

TABLE III  
*Inhibition of L- and S-Antibody by Degraded Forms of LS-Antigen*

Inhibiting solution	Ratio of inhibiting solution to antiserum	Anti-serum	Dilution of dermal filtrate					Saline + test mixture
			1 8	1 16	1 32	1 64	1 128	
None		L	++++	++++	++++	+++	++	
		S	++++	++++	++++	+++	++	
LS heated	1 1	L	+	-	-	-	-	-
	2 1	L	-	-	-	-	-	-
LS heated with alkali	1 1	L	++	++++	+++	++	++	-
	2 1	L	±	+++	+++	++	++	-
	1 1	S	-	-	-	-	-	-
	1/2 1	S	-	-	-	-	-	-
	1/4 1	S	±	+++	+	-	-	-
	1/8 1	S	++	++++	++++	+++	-	-

L-antiserum 1601 and S-antiserum 493 were used in the experiments summarized in this table.

See legend of Table II and text for details of experiment.

L-portion of the antigen, did not interfere with the union of the S-portion with its antibody and subsequent flocculation of the entire aggregate

*Experiment 8*—A portion of the solution of heated LS antigen used in Experiment 7 was freed of buffer by dialysis and treated with a sufficient amount of sodium hydroxide to bring the final concentration to 0.1 M. The material was heated in a water bath at 50°C in a closed vessel for 90 minutes with frequent gentle agitation. After neutralization to pH 7 the solution was titrated with S-antibody. The treatment failed to effect a complete loss of specific precipitability of the solution, for the S-titer, although much diminished, was still 1:320. Accordingly, the procedure was repeated except that 0.05 M concentration of alkali was used. Although the first treatment did not result in any change in the appearance of the solution, this second treatment was accompanied by the production of a small amount of insoluble material which, incidentally, was arranged in small, elongated ribbon-like fibers which were white in

reflected light and colorless in transmitted light. The insoluble material was removed and the solution tested in dilutions of 1:5 to 1:640 at pH 7 with optimal amounts of S-antibody. No precipitation occurred.

An inhibition experiment of the type described in the previous section was now performed. L- and S-antisera were treated with varying amounts of alkali, heat degraded antigen and subsequently tested for precipitable antibody. The results of the experiment are summarized in Table III.

It is apparent from the data presented in Table III that as little as 0.1 cc. of the solution of LS-antigen which had been degraded by heat and alkali (approximately 0.15 mg. of dried material) was sufficient to inhibit completely the S-antibody in the mixture. Furthermore, even  $\frac{1}{4}$  of this amount of antigen was sufficient to inhibit the antiserum slightly. On the other hand, 1.0 cc. (1.5 mg.) was incapable of inhibiting the amount of L-antibody employed. Thus, degradation of LS-antigen by means of heat and alkali completely destroys the serological activity of the L-portion of the molecule and changes the S-portion of the molecule to a form which no longer precipitates with S-antibody but is capable of inhibiting it. It will be noted that the inhibitory action of the degraded S-portion of the molecule on S-antibody is of a greater order of magnitude than that of the degraded L-portion for its corresponding antibody.

Electrophoretic studies on the solution of LS-antigen in Experiment 8 which had been degraded by heat and alkali showed that it contained one electrically homogeneous component with a mobility of  $6.4 \times 10^{-4}$  cm./sec. per volt/cm. at pH 7.9 and ionic strength 0.05. The mobility of this substance is close to that of component I in dermal filtrate. The two are not identical, however, for the latter failed to inhibit S-antibody. Furthermore, the two substances have different solubilities: the S-inhibitor is precipitated at pH 4.5 and fails to dissolve appreciably at pH 6.3, but it can be brought into solution between pH 8 and 9, and will then remain in solution when the pH is lowered to nearly 7.0.

#### DISCUSSION

The experiments presented in this paper indicate that all of the serological activity associated with the heat-stable and heat-labile soluble antigens of vaccinia are present in a single protein molecule. This differs somewhat from the concept of Craigie and Wishart (5), who considered the two antigens to occur, ordinarily, in the form of a complex which could be dissociated into two separate antigens under certain circumstances.

It is possible to state with assurance that various levels of degradation of LS-antigen can be accomplished, leaving either the L- or S part of the molecule in a stage where it can still combine with the corresponding antibody without precipitation. The observations on inhibition of L- and S-antibody reported in the previous paper were not sufficiently conclusive to enable us to decide as to the nature and origin of the inhibiting substances. On the basis of the

present studies it is clear that they arise directly from the LS-antigen through partial degradation of the molecule

Here it has been shown that the L-portion of the LS-molecule can be degraded by heat without serological alteration of the S-portion. In a subsequent paper in this series, it will be demonstrated that by means of enzymatic digestion the S-portion of the molecule can be degraded without altering the serological activity of the L-portion. On the basis of this latter observation it is possible to explain directly (2) the results occasionally obtained by other workers (4, 5), which had been interpreted (5) to indicate a dissociation of their LS-complex antigen into two separate components

#### SUMMARY

Virus-free filtrate, obtained from suspensions of vaccine virus-infected dermal pulp of rabbits and rich in the soluble substances of vaccinia, was shown to contain four distinct components in electrophoresis experiments. Electrophoretic and serological observations served as a guide in developing a method for separating these components from one another. This method depended upon changes in the solubilities of the components with alterations of pH.

Three of the four components appeared to be serologically inert when tested with anti-vaccinia sera. All of the L- and S-activity was found to be associated with a single component which was electrically homogeneous at several values of pH and which was homogeneous in the ultracentrifuge.

This single substance, designated as LS-antigen, precipitates in equal titers with optimal amounts of L- and of S-antibody and is completely removed from solution by absorption with either antibody.

The LS-antigen of vaccinia appears to be a protein molecule with two antigenically distinct parts, L and S. Heating modifies the L-portion in such a manner that the substance no longer precipitates with L-antibody, this degraded antigen still combines with L-antibody, as is shown by inhibition tests, and still precipitates with S-antibody. Similarly, treatment with heat and dilute alkali modifies the S-portion of LS-antigen so that it combines but does not precipitate with S-antibody, and at the same time all recognizable immunological properties of the L-portion are destroyed.

#### BIBLIOGRAPHY

1. Craigie, J., and Wishart, F. O., *J. Exp. Med.*, 1936, 64, 819
2. Smadel, J. E., and Rivers, T. M., *J. Exp. Med.*, 1942, 75, 151
3. Parker, R. F., and Rivers, T. M., *J. Exp. Med.*, 1937, 65, 243
4. Parker, R. F., *J. Exp. Med.*, 1938, 67, 361
5. Craigie, J., and Wishart, F. O., *J. Bact.*, 1938, 35, 25
6. Craigie, J., *Brit. J. Exp. Path.*, 1932, 13, 259
7. Longworth, L. G., Shedlovsky, T., and MacInnes, D. A., *J. Exp. Med.*, 1939, 70, 399

# THE EFFECT OF VARIOUS DIETS ON THE LIVER DAMAGE CAUSED BY EXCESS CYSTINE

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Previous reports (1-4) have described the rapid production of portal necrosis and hemorrhage in the livers of rats fed large amounts of *l*-cystine. In addition, more prolonged feeding of *l*-cystine causes the development of cirrhosis of the liver (4). The present paper is a study of the effects of variation in diet on the development of these liver lesions.

## Methods

Six different diets containing 10 gm. of *l*-cystine per 100 gm. of food (subsequently referred to as "10 per cent cystine") and 3 different diets containing 5 per cent cystine" were fed to male albino rats, 6 weeks of age. The protein of the 'synthetic' diets was supplied by casein and yeast, the fat by lard and cod liver oil or by butter, and the carbohydrate by sucrose. The relative amounts of these ingredients were varied in the different diets. Table I shows the composition of the diets, the average daily food consumption per rat, and the number of rats fed each diet. An additional series of rats was fed 5 and 10 per cent cystine in the McCollum stock diet.

These diets permitted a comparison of the effects of different protein, fat, carbohydrate, and yeast concentrations on the hepatic lesions produced by 10 per cent cystine. It was also possible to compare the effects of different kinds of fat, namely butter *versus* lard and cod liver oil, as well as the effects of synthetic diets *versus* the natural food McCollum stock diet. In the 5 per cent cystine group the McCollum stock diet was compared with a low protein, high lard, and cod liver oil diet. The effect of the addition of 1 per cent choline to this low protein, high fat diet was also examined.

The technique employed for classifying the liver lesions was similar to that described in a previous paper (4). Hemorrhage and necrosis were graded 0-4, each unit indicating involvement of  $\frac{1}{4}$  of the area of the section. Portal fibrosis and bile duct proliferation were also graded 0-4, each unit indicating involvement of  $\frac{1}{4}$  of the portal areas. In cases where there was any question as to the presence or absence of portal fibrosis, the Mallory connective tissue stain was employed. Hypertrophy and vacuolization of the liver cells were graded on the same basis as hemorrhage and necrosis. Estimation of the number of mitotic figures was made by counting the

number seen in 3 to 10 low power fields (magnification  $\times 100$ ) and obtaining the average per low power field

The fat content of the livers was determined by the method previously described (4)

TABLE I  
Per Cent Composition of Diets

Diet	10 per cent cystine						5 per cent cystine		
	10HL	10HB	10LF	10HP	10HY	10 S	5HL	5HLC	5 S
Type	Low protein High lard	Low protein High butter	Low fat Low protein	Low fat High protein	Low fat High yeast	McCollum stock	Low protein High lard	Low protein High lard + Choline	McCollum stock
<i>l</i> -Cystine	10	10	10	10	10	10	5	5	5
Salt mixture	4	4	4	4	4	*	4	4	*
Brewer's yeast	5	5	5	5	20		5	5	
Casein	5	5	5	40	5		5	5	
Lard	20	—	3	3	3		20	20	
Cod liver oil	5	—	2	2	2		5	5	
Butter	—	25	—	—	—		—	—	
Sugar	51	51	71	36	56		56	55	
Choline HCl	—	—	—	—	—		—	1	
No of rats	29	14	10	10	10	12	15	15	15
Intake, gm /rat	3 6†	3 8	3 0	3 0	3 3	3 8	6 1§	6 8	6 1

The number of rats fed each diet and the average daily intake of food are indicated below the dietary system. The *l*-cystine and the choline were obtained from the Eastman Kodak Co., Rochester, New York.

\* The McCollum stock diet (5) has the following composition in parts per cent: bran 67.5, whole milk powder 15, casein 10, butter 5, NaCl 1.5, and  $\text{Na}_2\text{CO}_3$  1.0

† Average of 10 rats only

§ Average of 7 rats only

## RESULTS

In Table II are summarized the per cent mortality, the incidence per cent of the liver lesions, and the average fat content of the livers of rats fed the several diets described. These features have been divided into 2 periods, namely, those occurring before and those after 2 weeks of the dietary regimen. The grouping of the data followed the general scheme outlined in Table I except that the groups fed 10 per cent cystine in the 3 low fat diets (low protein, high protein, and high yeast) were combined. These 3 groups showed no significant differences among themselves in their response to the 10 per cent cystine, with one exception which will be mentioned later. The mortality of the 10 per cent cystine groups during the first 2 weeks was calculated on the basis of the number of animals that died and that survived throughout the

period. The animals sacrificed during these 2 weeks were not considered in the calculation.

TABLE II

*Effect of Various Diets Containing 10 Per Cent or 5 Per Cent Cystine on Per Cent Mortality, Per Cent Incidence of Liver Lesions and Liver Fat Content*

Days on diet.	No. of rats		Per cent mortality		Per cent incidence liver lesions								Per cent fat content			
					Hemorrhage		Necrosis		Cirrhosis				2-14		15+	
	2-14	15+	2-14	15+	2-14	15+	2-14	15+	2-14	15+	Average	Range	Average	Range	Average	Range
10 per cent cystine in McCollum stock	10	2	78	—	20	—	50	—	41	12	2.2 (4)*	1.6-3.1	2.2	2.1-2.2		
10 per cent cystine in low fat	29	1	97	—	21	—	86	—	52	11	3.4 (20)	1.7-13.2	4.9			
10 per cent cystine in low protein high lard	22	7	71	—	73	29	77	71	14	71	4.0 (11)	2.5-7.9	15.3 (3)	13.1-19.1		
10 per cent cystine in low protein high butter	14	0	100	—	71	—	93	—	29	—	7.1 (12)	2.5-15.2				
5 per cent cystine in McCollum stock	5	10	0	0	0	0	60	20	80	50	1.4	1.1-2.0	2.6	1.4-5.0		
5 per cent cystine in low protein, high lard	5	10	0	0	0	20	0	70	0	40	13.6	4.8-17.4	23.5	7.6-42.3		
5 per cent cystine in low protein high lard + choline	5	10	0	0	0	0	20	20	40	30	4.3	1.6-11.4	2.4	0.8-4.6		

\* The numbers in parentheses represent the number of livers in the group analyzed for fat. In all other instances the entire group was analyzed.

The average amount of a specific lesion in a particular group of rats is equal to its percentage incidence multiplied by its average severity (calculated from data derived as described under Methods). On this basis, the average amount of hemorrhage, necrosis, and cirrhosis was calculated for the groups of rats that died or were sacrificed during the first 2 weeks on the various diets.



containing cystine In Fig 1, these values along with the average liver fat content are graphically presented

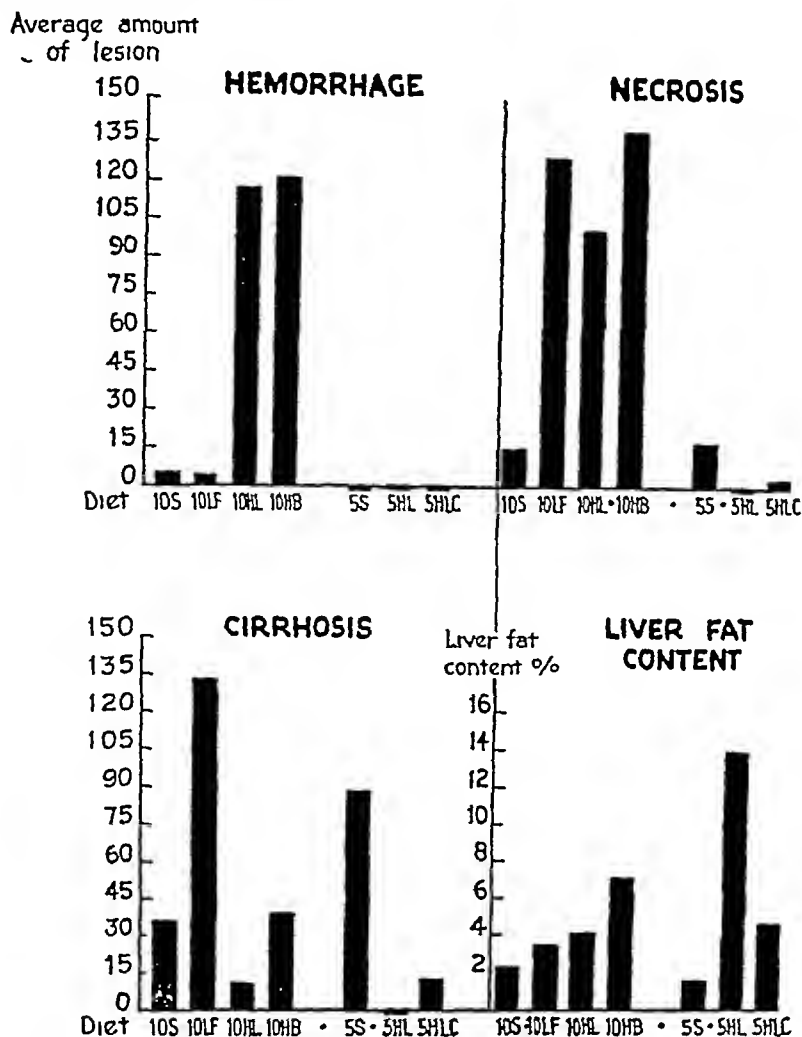


FIG 1 Effect of different diets on liver lesions due to excess dietary cystine First 2 weeks only. Ordinates represent average percentage incidence and average severity of liver lesion. Abscissa lists different diets, 10 = 10 per cent cystine, 5 = 5 per cent cystine, S = stock, LF = low fat, HL = high lard, HB = high butter, HLC = high lard and 1 per cent choline

*Effect of Diets on the Course and Liver Lesions Due to 10 Per Cent Cystine*

These data show that the diet modified the mortality rate and the character of the liver lesion resulting from 10 per cent cystine. If the McCollum stock

diet, the natural food diet, is considered as the basis for comparison, the following results are apparent

1 A low fat synthetic diet, regardless of the casein or yeast content was deleterious. This was indicated by a greater early mortality (only one of 30 rats lived more than 8 days) and by more necrosis and cirrhosis (Fig. 1). However, the incidence and severity of hemorrhage were not different.

2 A diet high in fat, consisting of lard 20 per cent, and cod liver oil 5 per cent had some protective action. This was indicated by a slightly lower mortality and a slower development of cirrhosis (bold faced figures, Table II). On the other hand, the incidence and extent of hemorrhage were far greater than that in the previous groups (McCullum stock and low fat diets). Necrosis was the same as in the low fat diets but greater than was observed in the McCullum diet.

3 The protective action of the high fat diet (lard 20 per cent and cod liver oil 5 per cent) was not due to fat alone, because 25 per cent butter substituted for the lard and cod liver oil, was followed by the most severe and harmful reaction to cystine. The mortality was greatest, the animals died in a shorter time (none survived more than 6 days), and hemorrhage and necrosis were most severe. In spite of the shorter survival period on this diet, these animals had much more cirrhosis in this 6 day interval than those on the 20 per cent lard and 5 per cent cod liver oil had in a 14 day interval.

#### *Effect of Diets on the Liver Lesions Due to 5 Per Cent Cystine*

Cystine was fed as 5 per cent of 3 different diets: the McCullum stock diet, the low protein, high lard, and cod liver oil diet, and the latter diet plus 1 per cent choline. There were 15 rats in each group. As none of these animals died, rats from each group were sacrificed after periods of from 3 to 42 days of cystine feeding. Five from each group were sacrificed during the first 2 weeks and 10 subsequently.

In general, the incidence and severity of the liver lesions were less than among rats fed 10 per cent cystine (Table II, Fig. 1) although the character of the lesion was the same. Portal hemorrhage occurred in only 2 of 45 rats fed 5 per cent cystine. Necrosis in the portal areas, when present, involved only a few cells.

Portal cirrhosis was present in each group and the incidence was modified by the diet (Table II and Fig. 2). Only 5 animals in each group were sacrificed during the first 2 weeks. There were insufficient data, therefore, to ascertain that the rate of development of cirrhosis was influenced by the diet. However, the available data indicate that the rate of development and the incidence of cirrhosis were related, that is, a rapid appearance of cirrhosis was associated with a high incidence of the lesion. Comparison of the 15 animals in each of the groups with those fed the 5 per cent cystine McCullum stock diet revealed the following with respect to the incidence of cirrhosis:

1 On the low protein, high lard, and cod liver oil diet the incidence was 4 of 15 as compared with 9 of 15 on the McCollum stock diet, that is, about one-half. During the first 2 weeks the incidence was 0 of 5 as compared with 4 of 5. In other words, the low protein, high lard diet had a protective action against the development of cirrhosis produced by either 5 per cent or 10 per cent cystine.

2 Addition of 1 per cent choline to the low protein, high lard, and cod liver oil diet did not significantly alter the protective effect of this diet, that is, 5

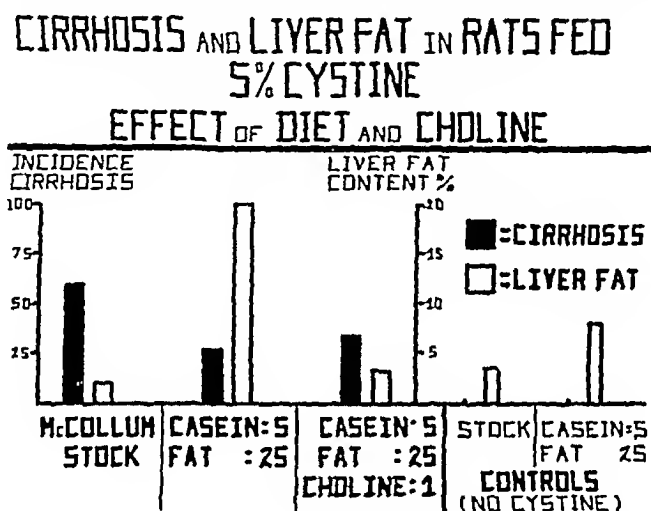


FIG 2 There is no correlation between severity of fatty infiltration and cirrhosis in rats fed 5 per cent cystine. Choline, which prevented the fatty infiltration due to the diet, did not inhibit the development of cirrhosis. The incidence of cirrhosis was greatest on the McCollum diet, while the fatty infiltration was least.

of 15 fed choline had cirrhosis as compared with 4 of 15 on the diet without choline.

#### *Effect of Diet on the Fat Content of the Livers of Rats Fed Excess Cystine*

The average fat content of livers of 12 rats on the McCollum diet without cystine was 3.5 per cent (range 3.0-4.5). None of these control livers showed evidence of necrosis or cirrhosis. The average liver fat content of rats fed 5 per cent or 10 per cent cystine in the McCollum stock diet was 2.2 per cent. Although the livers of a few rats fed 10 per cent cystine in the low fat diets had slight increases in fat content, the average value was within the normal limits described above (Table II).

In contrast to the above, the average liver fat content of 8 rats on a low protein, high lard, and cod liver oil diet without cystine for 3 to 40 days was 8.1 per

cent (range 4.2-13.3) No liver lesions other than fatty infiltration occurred in this group. Addition of 10 per cent cystine to this low protein, high fat diet resulted in no further increase in the liver fat content in rats that survived more than 2 weeks. The 5 per cent cystine diet, however, resulted in an earlier and greater fatty infiltration of the liver than 10 per cent cystine (Table II). It is likely that this is related to the total food intake rather than to cystine alone, for, as Table I indicates, the animals that received 5 per cent cystine ate twice as much food as those receiving 10 per cent cystine. Therefore, both groups ingested the same amount of cystine, but the 5 per cent group ate twice as much fat.

The fatty infiltration observed with 5 per cent cystine in the high fat diet was inhibited by the addition of 1 per cent choline.

#### *The Relationship of Fatty Infiltration and Cirrhosis of the Liver Due to Excess Dietary Cystine*

The results described above offer an opportunity to determine any correlation between liver fat content and the development of cirrhosis in rats fed excess cystine. In these experiments, the diet modified both of these characteristics and if there were any causal relationship between them, the fatty infiltration and the cirrhosis should have shown some correlation.

Fig. 2 shows the incidence of portal cirrhosis of the liver and the average liver fat content of groups of 15 rats fed 5 per cent cystine in the McCollum stock diet, a low protein-high fat diet and a low protein high fat diet plus 1 per cent choline. Cirrhosis was found in 60 per cent of the McCollum stock diet group and the average liver fat content was only 2.2 per cent. Although 1 per cent choline added to the low protein, high fat, and cod liver oil diets greatly lowered the liver fat content, i.e. from 20.7 per cent without choline to 3.0 per cent, it did not influence the incidence of cirrhosis which was approximately 30 per cent, with or without choline.

Fig. 3 is a scatter chart of the fat content and the severity of cirrhosis in the livers of rats fed excess cystine in the various diets.

No correlation between the liver fat content and the incidence or severity of cystine cirrhosis was evident from the above data.

#### *Other Findings*

Hypertrophy and vacuolization of the liver cells were found in each group. In general the incidence and severity of these features paralleled the degree of fatty infiltration. However, in a number of instances, the liver cells had hydropic vacuoles and the liver fat content was normal or low. In these cases, the vacuoles did not take up Sudan III.

All livers were studied for the presence of mitotic nuclei. In contrast to the other rats, many mitotic nuclei were found only among the rats fed cystine

as 10 per cent of the low fat, high *protein* diet. Among the rats fed 5 per cent cystine, no mitoses were seen in the livers of the stock diet group, but were observed in a few of those receiving low protein and high fat, with or without 1 per cent choline.

### LACK OF CORRELATION BETWEEN LIVER FAT CONTENT AND INCIDENCE OF CYSTINE CIRRHOSIS

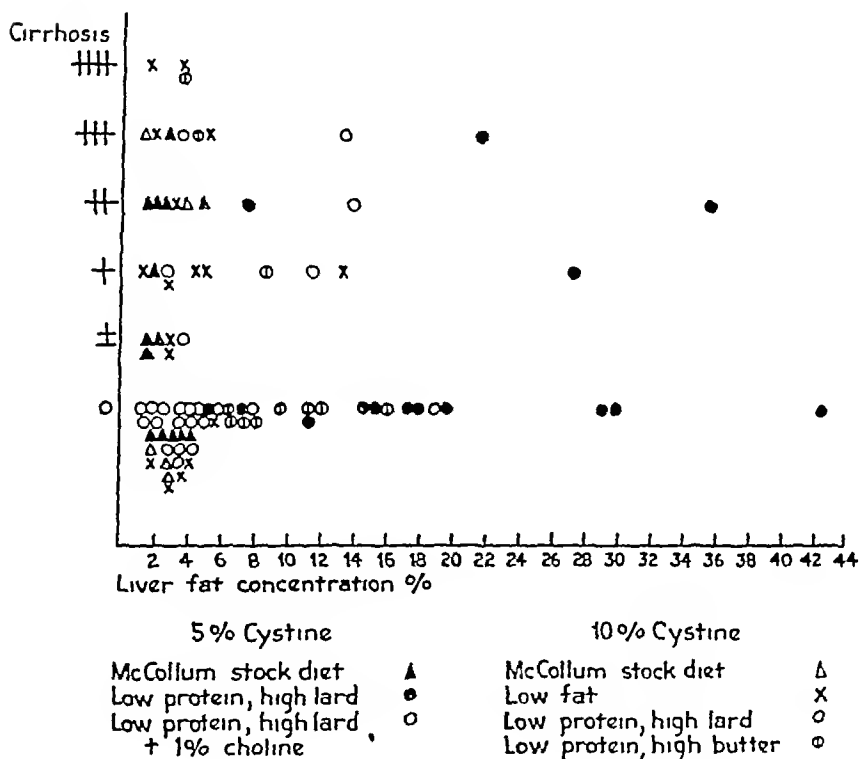


FIG 3 Scatter chart showing degree of cirrhosis and fat content of the livers of rats fed excess cystine in various diets. For cirrhosis ± = fibrosis of less than  $\frac{1}{4}$  of the portal areas, + = fibrosis in  $\frac{1}{4}$  of the portal areas, ++ = fibrosis in  $\frac{1}{2}$  of the portal areas, and so on.

In a few instances, where severe liver damage had resulted from excess dietary cystine, enlargement of the spleen with congestion and fibrosis was noted.

Of 130 rats fed cystine as 5 or 10 per cent of various diets, hemorrhagic kidneys were found but once.

### Summary of Results

*Hemorrhage* in the liver was most severe with a high fat intake, whether the fat was lard and cod liver oil or butter. *Necrosis* was more severe with synthetic diets, regardless of the proportions of fat, protein, carbohydrate, or yeast, than with the natural food diet. *Cirrhosis* was less severe during the first 2 weeks on the high lard and cod liver oil diet than on the high butter, or low fat, or the McCollum diets. *Fatty infiltration* in the livers of rats fed excess cystine was also modified by diet. There were slight increases in the liver fat content of only a few rats on the McCollum stock and low fat diets. Marked increases were noted in the low protein, high fat groups. This increase in liver fat was prevented by 1 per cent choline. The number of *mitotic nuclei* in the liver cells was greatest among the rats fed the high protein, low fat diet. In other words, not only is the degree of cystine damage to the liver affected by diet, but the pathogenesis of the lesion is also dependent on the diet.

### DISCUSSION

The differences in liver lesions produced by cystine fed in various diets were related to differences in the diets and not to differences in consumption of cystine. The average daily food consumption of the rats fed 10 per cent cystine was essentially the same with all diets (Table I). The food consumption of rats fed 5 per cent cystine was approximately twice that of rats fed 10 per cent cystine, so that all groups consumed the same amount of cystine.

It is possible, though not probable, that there were differences in the amounts of cystine absorbed from the gastrointestinal tract on the various diets. In this connection it should be noted that Wilson (6) found that rats could absorb cystine from the gastrointestinal tract at the rate of 30 mg per hour, or 720 mg in 24 hours. In the present experiments, the greatest amount of cystine consumed by an individual rat in 24 hours was 630 mg, while the average intake for the groups of rats on the different diets varied from 300 to 380 mg in 24 hours.

The liver lesions produced by cystine are related to the proportion of cystine in the diet but not to the amount of cystine ingested. This is illustrated by the fact that there were differences in the liver lesions between rats fed 5 per cent and 10 per cent cystine (Table III), although both groups ingested the same amount of cystine, the food consumption of rats fed 5 per cent cystine being twice that of rats fed 10 per cent cystine (Table I).

It has been reported that high dietary fat enhances the deleterious effect of various hepatotoxins (7-12) or may produce cirrhosis (19, 20). The present studies indicate that certain fats such as lard and cod liver oil, when fed as 25 per cent of the diet, have some protective effect against liver damage caused

by excess cystine, while butter does not. In liver damage due to selenium, it has been found that a diet containing 39 per cent beef fat and 2 per cent cod liver oil protected against the development of cirrhosis of the liver (13).

Most of the reported studies state that protein (8-12) and yeast (14) are protective against certain liver poisons. In the present experiments, liver damage resulting from 10 per cent cystine in low fat diets was not influenced by 5 or 40 per cent casein or by 5 or 20 per cent brewer's yeast. The studies reported in this paper agree with the findings that yeast *per se* has no protective action on carbon tetrachloride liver damage when the food intake is controlled (15).

Gyorgy and Goldblatt (16) have found necrosis and cirrhosis of the liver in rats fed, for 100 or more days, a diet devoid of vitamin B, but supplemented with thiamine, riboflavin, pyridoxine, and pantothenic acid. The diet was also low in protein (casein 10 per cent) and high in fat (lard 20 per cent, cod liver oil 2 per cent). The addition of small amounts of cystine increased the severity of liver damage while choline prevented it. Similar findings were reported by Blumberg and Grady (17). More recently, Webster (18) has reported necrosis and cirrhosis in rats fed low protein, high fat diets which also contained adequate amounts of brewer's yeast. These lesions were made more severe by the addition of small amounts of cystine and were prevented by choline. The present experiments show that the liver damage caused by 5 per cent cystine fed in a 5 per cent casein, 20 per cent lard, and 5 per cent cod liver oil diet was not prevented by 1 per cent choline, although the fatty infiltration of the liver was markedly inhibited (Fig. 2).

This difference in the response to choline is a distinction between the pathogenesis of the liver lesion produced by cystine and that caused by low protein high fat diets (16-20). Other differences are found in the liver lesions as well as in the rate of their development. On the cystine diet, the lesions originated in the portal areas while those described by György and Goldblatt (16) showed diffuse degeneration. The cirrhosis caused by cystine may appear within a week, while under the conditions summarized above (16-18) about 4 months on the diet were required for the appearance of cirrhosis. The cirrhosis caused by cystine was associated with considerable bile duct proliferation (4) and not necessarily with fatty infiltration. That found under conditions mentioned by others (16-20) had considerable fatty infiltration and little bile duct reaction, even when small quantities of cystine were added to the diet (16).

#### SUMMARY AND CONCLUSIONS

- 1 The effect of 9 different diets on the liver lesions resulting from excess dietary cystine has been studied in 130 rats.
- 2 The incidence and severity of each of the following liver lesions were

varied by changes in the composition of diets containing 5 or 10 per cent cystine

(a) *Hemorrhage* was least severe with low fat diets

(b) *Necrosis* was most severe with synthetic diets

(c) *Cirrhosis* was delayed by a diet high in lard, 20 per cent, and cod liver oil, 5 per cent, but not by a diet high in butter, 25 per cent.

(d) *Fatty infiltration* was found consistently only with low protein, high fat diets

In other words, the pathogenesis of the liver lesion due to excess dietary cystine can be modified by diet.

3 In the presence of cystine as 5 per cent of a low protein, high fat diet, 1 per cent choline inhibited fatty infiltration but did not protect the liver against damage by cystine

4 In these experiments there was no apparent correlation between fatty infiltration of the liver and the incidence or degree of cirrhosis

#### BIBLIOGRAPHY

- 1 Curtis, A. C., and Newburgh, L. H., *Arch. Int. Med.*, 1927, 29, 828
- 2 Sullivan, M. Y., Hess, W. C., and Sebrell, W. A., *Pub. Health Rep., U. S. P. H. S.*, 1935, 47, 75
- 3 Lillie, R. D., *Pub. Health Rep., U. S. P. H. S.*, 1935, 47, 83
- 4 Earle, D. P. and Victor, J., *J. Exp. Med.* 1941, 73, 161
- 5 Evans, H. M., and Bishop, K. S., *J. Metabol. Research*, 1922, 1, 319
- 6 Wilson, R. H., *J. Biol. Chem.*, 1930, 87, 175
- 7 Opie, E. L., and Alford, L. B., *J. Am. Med. Assn.*, 1914, 62, 895
- 8 Davis, N. C., and Whipple, G. H., *Arch. Int. Med.*, 1919, 23, 612
- 9 Davis, N. C., *J. Med. Research* 1924, 44, 601
- 10 Goldschmidt, S., Vars, H. M., and Ravdin, I. S., *J. Clin. Inv.*, 1939, 18, 277
- 11 Miller, L. L., and Whipple, G. H., *Am. J. Med. Sc.*, 1940, 199, 204
- 12 Messinger, W. J., and Hawkins, W. B., *Am. J. Med. Sc.*, 1940, 199, 216
- 13 Smith, M. L., *Pub. Health Rep., U. S. P. H. S.*, 1939, 54, 1441
- 14 Von Glahn, W. C., and Flinn, G. B., *Am. J. Path.*, 1939, 15, 771
- 15 Post, J., Earle, D. P., Patek, A. J., and Victor, J., to be published.
- 16 György, P., and Goldblatt, H., *Proc. Soc. Exp. Biol. and Med.*, 1941, 48, 492
- 17 Blumberg, H., and Grady, H. G., read before the American Society for Experimental Pathology April 19, 1941
- 18 Webster, G., read before the American Society for Clinical Investigation, May 5, 1941
- 19 Chaikoff, W. L., and Connor, C. L., *Proc. Soc. Exp. Biol. and Med.*, 1940, 43, 638
- 20 Lillie, R. D., Daft, F. S., and Sebrell, W. H., *Pub. Health Rep., U. S. P. H. S.*, 1941, 56, 1255





# LIVER DAMAGE AND URINARY EXCRETION OF SULFATE IN RATS FED *L*-CYSTINE, *DL*-METHIONINE, AND CYSTEIC ACID

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It has been reported that rats fed *L*-cystine as 5 or 10 per cent of the diet develop portal necrosis and hemorrhage of the liver (1-4). In addition, more prolonged feeding of *L*-cystine results in portal cirrhosis of the liver (4). It has been shown that the metabolism of *L*-cystine (5) and *DL*-methionine (6) results in the urinary excretion of the greater part of the sulfur contained in these amino acids as sulfate. Schmidt and Clark (7), however, have demonstrated that the sulfur of cysteic acid is not oxidized by the animal organism but is excreted in the neutral sulfur fraction of the urine.

If the formation and excretion of large amounts of sulfate resulting from the metabolism of *L*-cystine were the cause of the liver lesions previously described, then *DL*-methionine fed in excess amounts should also result in liver damage. Cysteic acid, on the contrary, should not have this effect. The present paper is a report of experiments in which this hypothesis was put to the test.

## Methods

The sulfur-containing amino acids, *L*-cystine and *DL*-methionine were obtained from the Eastman Kodak Co. The cysteic acid was prepared from *L*-cystine by the bromine oxidation method and was neutralized by NaOH before administration.

The sulfur-containing compounds were thoroughly mixed into either the McCollum stock diet or a low protein, high fat diet of the following composition: in grams per 100 gm. of food: casein 5, butter 25, brewers yeast 5, salt mix 4, and sugar *ad libitum*. These diets were then fed to albino rats and the daily intake noted. At intervals 24 hour urine collections were made for urinary sulfur partitions (8) as well as ammonia determinations. In addition blood for CO<sub>2</sub>-combining power values was obtained at the time of sacrifice. Finally, microscopic sections of the liver of each rat were studied for the presence or absence of necrosis and cirrhosis. These features, when present, were graded on the basis of + to +++++ (4).

The protocols of the 15 rats studied are presented in Table I. The urine collections periods for rats 9, 14, and 15 were divided between the first and last days of

the experiment. In all other instances, the collection periods were made consecutively during the last days on the experimental data.

## RESULTS

The intake of sulfur and the total sulfur, sulfate sulfur, and ammonia nitrogen urinary excretion figures are given in Table II. These figures represent the averages of the values obtained for each rat in the number of collection periods indicated in Table I, and are recorded as milligrams per 100 gm. of rat per 24

TABLE I

*Weight, Diet, Days on Diet, Number of Balance Periods, and Outcome of Rats Fed Sulfur Containing Compounds*

Rat No	Weight at start	Basal diet	Sulfur compound fed		Days on diet	No of collection periods	Outcome
			Compound	Per cent of diet			
1	184	Low protein, high fat	<i>l</i> Cystine	10	3	3	Died
2	72	" " " "	"	10	4	4	Sacrificed
3	96	" " " "	"	10	3	3	"
4	190	" " " "	"	10	4	4	"
5	79	" " " "	"	5	34	6	"
6	90	" " " "	"	5	34	6	"
7	116	" " " "	"	5	38	4	"
8	92	McCullum stock	"	5	38	4	"
9	90	" "	"	5	38	6	"
10	71	Low protein, high fat	<i>dl</i> Methionine	12.8	6	5	"
11	52	" " " "	"	6.4	6	5	Died
12	224	McCullum stock	"	10	12	2	Sacrificed
13	278	" "	"	10	12	2	"
14	112	McCullum stock	Cysteic acid	15	10	2	"
15	71	" "	" "	15	15	3	"

hours. The per cent of sulfate neutralized by ammonia and the blood CO<sub>2</sub>-combining power values are also given in Table II.

The urinary excretion of sulfur was studied in 6 of the rats on the basal low protein, high fat diet before the addition of the sulfur compounds. The average excretion in 12 control periods was 6.7 mg. of total sulfur and 3.3 mg. of sulfate sulfur per 100 gm. rat per 24 hours. The corresponding figures for 5 control periods in 3 rats on the basal stock diet were 11.2 mg. and 7.3 mg. The excretion figures for sulfur given in Table II were not corrected for these control values as the food intake and body weight declined during the periods of *l*-cystine and *dl*-methionine feeding. From the available data it was im-

possible to calculate how much of the sulfur excreted during the experimental periods was derived from exogenous and how much from endogenous stores. In any case, the control values were relatively small when compared to the experimental figures and the results do not appear to be invalidated by excluding the control values from the calculations.

From Table II it may be seen that the rats fed excess *l*-cystine or *dl*-methionine excreted relatively huge amounts of sulfate sulfur while the rats fed

TABLE II  
Summary of Chemical Data of Rats Fed Sulfur-Containing Compounds

Rat No	Sulfur compound fed			Urine				Blood CO <sub>2</sub> -combining power	
	Compound	Per cent of diet	Intake sulfur*	Total sulfur*	Sulfate sulfur*	Ammonia nitrogen	SO <sub>4</sub> neutralized by NH <sub>4</sub>	per cent	per cent
1	<i>l</i> Cystine	10	94	32	16	—	—	—	—
2		10	126	79	40	—	—	—	55
3		10	160	86	43	31	82	—	36
4		10	57	37	18	15	92	—	40
5	"	5	76	68	42	25	71	—	41
6		5	49	53	29	17	65	—	43
7		5	90	102	62	49	80	—	36
8		5	91	90	67	48	81	—	37
9		5	83	86	54	47	92	—	—
10	<i>dl</i> Methionine	12.8	85	66	32	32	70	—	—
11	"	6.4	42	42	38	31	90	—	—
12		10	40	36	27	14	61	—	42
13		10	31	22	17	7	44	—	37
14	Cysteic acid	15	150	88	15	21	164	—	—
15		15	211	151	18	31	138	—	—

\* Figures in these columns represent mg. per 100 gm. of rat per 24 hours.

cysteic acid formed much smaller amounts of sulfate. These results are in accord with many other published studies of a similar nature (5-7). Enough sulfate was excreted by the rats fed *l*-cystine and *dl*-methionine to require large amounts of base for neutralization. It might be expected that this, continued over a considerable length of time, would be a serious drain on the rats' reserves of base. The blood CO<sub>2</sub>-combining power determinations, however, showed no or moderate decreases from normal values. This is probably explained by the capacity of these animals to form large amounts of ammonia. As shown in Table II, sufficient ammonia was present in the urine of rats fed

*l*-cystine or *dl*-methionine to neutralize as much as 92 per cent of the sulfate excreted

The degree of necrosis and cirrhosis present in the livers of the rats is recorded in Table III. Hepatic necrosis and/or cirrhosis was noted in each of the rats fed *l*-cystine and cysteic acid. Although the livers of the rats fed *dl*-methionine were very small and microscopic examination revealed atrophy of the liver cells, necrosis and cirrhosis were not found. Twenty additional rats were fed *dl*-methionine at excessive levels in various diets. No cirrhosis was found in any of these, while a few isolated necrotic cells were seen in the

TABLE III  
*Liver Damage in Rats Fed Sulfur-Containing Compounds*

Rat No	Compound fed	Per cent of diet	Liver lesions	
			Necrosis	Cirrhosis
1	<i>l</i> Cystine	10	+++	0
2	"	10	+	+
3	"	10	++	+
4	"	10	0	+
5	"	5	+	+++
6	"	5	0	++
7	"	5	0	+++
8	"	5	+	++
9	"	5	0	+
10	<i>dl</i> -Methionine	12.8	0	0
11	"	6.4	0	0
12	"	10	0	0
13	"	10	0	0
14	Cysteic acid	15	+	++
15	" "	15	+	++

liver of one rat only. A more detailed description of the effects of feeding *dl*-methionine and cysteic acid to rats will be given in another communication.

#### SUMMARY

1 Rats fed *l*-cystine at excessive levels excrete large amounts of sulfate sulfur in the urine and develop liver necrosis and cirrhosis.

2 Rats fed *dl*-methionine at excessive levels excrete large amounts of sulfate sulfur, but do not develop liver necrosis and cirrhosis.

3 Rats fed cysteic acid at high levels excrete relatively small amounts of sulfate, but do develop liver necrosis and cirrhosis.

4 In conclusion, there is no apparent correlation between the amount of

sulfate formed and the development of liver damage in rats fed *L*-cystine, *dl*-methionine, and cysteic acids

## BIBLIOGRAPHY

- 1 Curtis, A. C., and Newburgh, L. H., *Arch Int Med*, 1927, **29**, 828
- 2 Sullivan, M. A., Hess, W. C., and Sebrell, W. A., *Pub Health Rep, U S P H S*, 1935, **47**, 75
- 3 Lillie, R. D., *Pub Health Rep, U S P H S*, 1935, **47**, 83
- 4 Earle, D. P., and Victor, J., *J Exp Med*, 1941, **73**, 161
- 5 Blum, L., *Beitr chem Physiol u Path*, 1904, **5**, 1
- 6 Virtue, R. W., and Lewis, H. B., *J Biol Chem*, 1934, **104**, 59
- 7 Schmidt, C. L. A., and Clark, G. W., *J Biol Chem*, 1922, **53**, 193
- 8 Fiske, C. H., *J Biol Chem*, 1921, **47**, 59



# CELL STATE AS AFFECTING SUSCEPTIBILITY TO A VIRUS

## ENHANCED EFFECTIVENESS OF THE RABBIT PAPILLOMA VIRUS ON HYPERPLASTIC EPIDERMIS

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PLATES 2 AND 3

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The effects of some viruses are known to be altered when they act upon cells which have been previously rendered abnormal. The virus of herpes simplex induces lesions resembling those of herpes zoster in rabbit skin altered by tar (1), and ultraviolet irradiation of rabbit skin modifies the local susceptibility to inoculation with vaccine virus (2). The Shope papilloma virus (3) elicits carcinomas forthwith, as well as various papillomas of unusual sort, when it is brought into association with the epidermis of domestic rabbits, which has been tarred for some weeks (4). The experiments reported in the present paper were undertaken to learn whether preliminary alterations of rabbit epidermis would provide a more favorable soil for the demonstration of the papilloma virus. Often no virus can be got from the papillomas of domestic rabbits directly produced therewith though its presence in the growths is readily demonstrable serologically (5, 6) as also in the cancers deriving from them (7).

### *Material and Methods*

Papilloma virus was obtained from the naturally occurring growths of cottontail rabbits which had been preserved in 50 per cent glycerin Locke's solution at about 4 C. Weighed portions of the tissue were passed through several changes of saline ground with sand, and suspended in 10 to 20 volumes of 0.9 per cent saline. The crude extracts thus obtained were spun in an angle-head centrifuge at about 3500 R.P.M. for 5 minutes and the supernatant fluids were again spun at about 4500 R.P.M. for 20 minutes. They were now clear amber and were usually highly infectious as such and after filtration through Berkefeld V candles. For test they were inoculated intradermally or rubbed into the skins of adult domestic rabbits of the gray brown (agouti) breed or cottontail rabbits (genus *Sylvilagus*) after scarification with sand paper according to a method already described (5, 6). The character of the papillomas arising was recorded at frequent intervals from the 8th day to about the 42nd day after inoculation according to a standard scale: ++++ = confluent papillomatosis, +++ = semiconfluent papillomatosis, ++ = many discrete papillomas, + = 5 to 15 papillomas, ± = 2, 3 or 4 papillomas, 1 = 1 papilloma, 0 = negative.



To conserve space, the readings of only a few days are given in the tables. They are representative of the findings as a whole.

### *Influence of Carcinogenic Agents to Alter Skin Susceptibility*

In a first experiment the results of rubbing a suspension of papilloma virus into scarified skin were compared with those consequent on infiltrating tarred rabbit ears with the suspension by way of a marginal vein.

*Experiment 1*—The ears of fourteen normal cottontail rabbits were tarred over the inner and outer surfaces on three occasions at intervals of 3 or 4 days. This amount of tarring caused the ears to become acutely inflamed, thickened, and moist, but elicited no tumors. A strong rubber band was placed about the base of the ear, to stop the circulation, and 5 cc. of a virus filtrate (W R 1-28) diluted from 1:500 to 1:480,000,—in terms of the papilloma material originally extracted,—was then slowly injected into a marginal vein of the ear. The rubber bands were removed 5 minutes after injection. The ears of each rabbit received different dilutions of the virus. 0.2 cc. of the same dilutions was then rubbed into scarified areas of normal skin on the abdomens of the same rabbits.

The results can be briefly summarized. Six of the rabbits proved resistant to infection, only a few growths arising from either the tarred or the normal epidermis. Eight rabbits were susceptible and in every one many more papillomas developed from the tarred epidermis than from the normal skin inoculated with the same dilution of virus. The ratio of the number of papillomas on the tarred skin to that on the normal skin was as high as 135 or more to 1. Furthermore papillomas were elicited in the tarred ears by a considerably higher dilution of virus. In one instance a dilution of 1:80,000 elicited papillomas on the tarred epidermis, yet 1:500 failed to do so on the untreated skin. In five animals papillomas appeared on the tarred ears and none on the scarified skin in response to the same dilution of virus. All of the growths were benign papillomas.

The findings indicate that rabbit skin to which tar has been applied a few times is more susceptible to infection with the papilloma virus than normal scarified skin. The objections can be raised, however, that the total amount of virus introduced into the tarred ears was greater than that rubbed into the skin of the abdomen and that neither the skin situations nor the methods of inoculation were comparable. To control these variables an experiment was done next in which virus was rubbed into areas of skin, some of which had been tar-treated while others had been left untreated prior to scarification. As enlarging the test, other areas which had been treated previously with methylcholanthrene or benzpyrene were inoculated with virus.

*Experiment 2*—The hair was clipped from twelve rectangular areas of skin measuring about  $3 \times 5$  cm. on the abdomens of four domestic rabbits. Small hairy strips were left between the areas which were in three anteroposterior rows of four areas each. One area of each row was painted with a carcinogenic tar, another with 0.3

per cent methylcholanthrene in benzene, and a third patch with 0.3 per cent benzpyrene in benzene.<sup>1</sup> Small camel's hair brushes were used to apply the agents. The remaining area of each row served as control. The situations of the control and treated areas were varied from animal to animal. After each treatment they were covered individually with sterile gauze pads, moored with adhesive to prevent spread of the reagents, after which a gauze pad and many tailed binder were put over all. The skin treatments were repeated twice per week for 2 weeks. They elicited no tumors.

Two days after the last treatments the patches were greatly changed. Those that had been tarred showed on stripping an acutely inflamed and thickened epidermis covered with a moist yellowish brown scurf. The methylcholanthrene-treated skin was also inflamed and greatly thickened, but less so, and was covered with a dry brown scurf. The benzene treated skin had a similar appearance. To learn the nature of the changes a narrow slice of a normal area and of each of the treated patches was taken under ether anesthesia from each rabbit, fixed in acid Zenker solution and stained with eosin and methylene blue.

Immediately after the biopsies the areas were scarified with sandpaper and a 0.5 per cent virus extract (W.R. 1-28) was rubbed into one row of the normal and treated skin areas, and another similarly prepared extract (W.R. 11-69) into another row. The treated areas proved more difficult to scarify than the normal skin, the tar treated areas especially, because of the moist adherent scurf. Immediately after inoculation the patches were dried in a blast of warm air and bandaged as before.

The results of the experiment are shown in Table I. The findings with the two virus extracts can be considered together. On the 10th day after virus inoculation, discrete papillomas had appeared on most of the methylcholanthrene treated skin areas and on a few of the benzpyrene- and tar treated areas. No growths were visible on the normal skin at this time. By the 15th day the papillomas on the treated skin areas had greatly increased in number and had enlarged rapidly, many of them now being semiconfluent papillomatous masses. The normal skin areas, on the other hand, showed relatively few papillomas and they were small and discrete. On the 20th day most of the treated skin areas showed large, vigorous confluent or semiconfluent papillomatous masses up to 1.0 cm. high while the growths on the normal skin were still discrete, in some instances just appearing and only occasionally were as much as 0.3 cm. high. The papillomas on the treated patches were in many instances dark gray while those on the healed normal skin of the same animal were pink or light gray. All were ordinary virus-induced papillomas.

The experiment shows (Table I) that a few preliminary applications to rabbit skin of tar, benzpyrene, or methylcholanthrene greatly enhance the susceptibility of the skin to papilloma virus infection. Growths appeared earlier in the treated skin, were more numerous, tended to be more pigmented.

<sup>1</sup> The tar came from the Oostergasfabrik of Amsterdam, and was the generous gift of Dr. Karl Landsteiner. It has been employed in much work in this laboratory. The methylcholanthrene was obtained from the Eastman Kodak Company and the benzpyrene from Hoffmann-La Roche Inc.

and grew more rapidly, forming large papillomatous masses at a time when the growths in the normal skin were just appearing or were still small and discrete. Similar findings were obtained in another experiment when virus was inoculated into normal and methylcholanthrene-treated skin by means of a tattoo machine (Figs 6 and 7)

TABLE I

*Susceptibility to the Papilloma Virus of Normal Skin and Skin Treated with Carcinogenic Agents*

Papilloma virus extract	Agent applied to skin before virus inoculation*	Pathogenicity tests											
		10th day				15th day				20th day			
Test rabbits		a	b	c	d	a	b	c	d	a	b	c	d
Λo	Normal skin	0	0	0	0	+	±	±	±±	++	++	±±	±±±
W.R. 128 (0.5 per cent)	Tar	0	0	0	+	±±	±±±	+	±±±	±±±±	±±±±	±±±	±±±±
	Benzpyrene	+	0	0	±	±±±	±±±	±±	±±±±	±±±	±±±±	±±±±	±±±±
	Methylcholanthrene	±±	±	±	±±	±±±	±±±	±±±	±±±±	±±±±	±±±±	±±±±	±±±±
W.R. 11-69 (0.5 per cent)	Normal skin	0	0	0	0	+	±	±	±±	++	±±	+	±±
	Tar	0	0	0	0	±	±±±	±	±±±	++	±±±±	++	±±±±
	Benzpyrene	0	0	0	±	++	±±±	+	±±±	±±±±	±±±±	±±±	±±±±
	Methylcholanthrene	+	±	0	±	±±±	±±±	±±	±±±	±±±±	±±±±	±±±	±±±±

\* Benzpyrene and methylcholanthrene (0.3 per cent in benzene) and tar applied twice per week for 2 weeks. Virus inoculated 2 days after last treatments.

++++ = confluent papillomatosis

+++ = semiconfluent papillomatosis

++ = many discrete papillomas

± = 5 to 15 papillomas

±± = 2, 3, or 4 papillomas

± = one papilloma

0 = negative

### *Effect of Non-Carcinogenic Agents to Alter Skin Susceptibility*

The agents used in the preceding experiment were potent carcinogens, but were employed for so brief a period that they elicited no tumors. A test was next done to find whether non-carcinogenic agents, inflammatory for rabbit skin, would have the same effect.

*Experiment 3*—Twelve skin areas on the abdomens of four domestic rabbits were clipped as in Experiment 2. Three on each animal were painted with benzene as such and three others with 0.3 per cent methylcholanthrene in benzene three times per week for 2 weeks. Three more areas were exposed to 1500 r of x-ray irradiation 48 hours before virus inoculation. The rabbits were protected by flexible lead foil during irradiation, leaving only the areas exposed, and the rays came from a single tube run at 5 milliamperes and at a peak voltage of 135 kilovolts, without filtration.

The distance from tube to skin was 50 cm. The three remaining skin areas served as controls. A representative piece of the normal and treated skin areas was taken for microscopic study 2 days after the last treatments. The methylcholanthrene-treated skin showed the same gross changes described in Experiment 2. A 5 per cent virus filtrate (W.R. 1-30) was then rubbed into one area of each sort after scarification and into another after dilution of the filtrate to 0.1 per cent. The inoculations were made immediately after the biopsies.

Table II shows the results of the experiment. On the 12th day after virus inoculation the benzene- and methylcholanthrene-treated patches inoculated with 0.1 per cent filtrate showed discrete papillomas in three of the four test rabbits. No growths could be seen on the normal or x-rayed skin areas at this time. All of the areas inoculated with 5 per cent filtrate showed papillomas; the growths on the methylcholanthrene-treated areas being large, semiconfluent masses in contrast to the few small discrete growths just appearing on the normal and x-rayed patches. Many more discrete papillomas were present on the benzene-treated areas than on the normal skin, but they were fewer in number and smaller than on the skin areas which had received methylcholanthrene. By the 35th day the papillomas on the benzene- and methylcholanthrene-treated areas inoculated with the dilute filtrate had developed into confluent and semiconfluent papillomatous masses, whereas the growths on the normal and x-rayed skin areas produced with the same inoculum were still small and discrete though increasing in number. The skin areas inoculated with 5 per cent filtrate all showed confluent papillomas, but those on the normal and x-rayed patches were low mounds, up to 0.6 cm. high, whereas on the benzene-treated areas they were jagged peaks up to 1.0 cm. high and on the skin treated with methylcholanthrene they were up to 1.6 cm. high. The last mentioned growths were deeply pigmented, while the others were pink or merely streaked with gray. Microscopic sections of the growths showed them all to be ordinary papillomas.

To extend the findings another experiment was done. This time the skin areas were treated with ultraviolet light, methylcholanthrene, and a mixture of turpentine and acetone.

*Experiment 4*—A mixture of turpentine and acetone in equal parts,—which had proved non-carcinogenic (8),—was applied to three clipped areas on the abdomens of four domestic rabbits five times at 2-day intervals and 0.3 per cent methylcholanthrene in benzene in like manner to another three. Three other areas were exposed to a quartz mercury vapor lamp<sup>2</sup> for 40 minutes at a distance of 25 cm. 48 hours before virus inoculation. This caused a marked erythema. Three untreated skin areas served as controls. The turpentine and acetone-treated skin became acutely inflamed, thickened and hyperkeratotic, as greatly changed in the gross as the methylcholanthrene-treated skin. A virus filtrate (W.R. 1-70) in concentrations of 0.1 per cent and 5 per cent was rubbed into two rows of the areas after scarification.

The results are shown in Table III. It will be seen that the papillomas on the methylcholanthrene- and turpentine and acetone-treated areas arose earlier and in

<sup>2</sup> Alpine sun lamp, Hanovia Chemical and Manufacturing Company

TABLE II

*Susceptibility of Normal Skin and Skin Treated with X-Rays, Benzene, and Methylcholanthrene*

Dilution of virus filtrate V.R. 1:30	Skin treatment before virus inoculation*	Pathogenicity tests											
		12th day				18th day				35th day			
		a	b	c	d	a	b	c	d	a	b	c	
1st rabbits													
per cent													
0.1	Normal skin	0	0	0	0	±	±	+	±	++	++	++	
	X rays	0	0	0	0	±	+	0	0	++	++	++	
	Benzene	+	+	0	+	++	++	++	++	++++	++++	++	
	Methylcholanthrene	±	+	0	±	++	++	+++	++	++++	++++	+++	
5	Normal skin	±	+	±	+	++	+++	+++	+++	++++	++++	+++	
	X rays	±	+	±	±	++	+++	+++	++	++++	++++	+++	
	Benzene	++	+++	++	++	++++	++++	++++	+++	++++	++++	+++	
	Methylcholanthrene	+++	+++	+++	+++	++++	++++	++++	++++	++++	++++	+++	

\* Benzene applied to skin areas three times per week for 2 weeks before virus inoculation

0.3 per cent methylcholanthrene in benzene applied three times per week for 2 weeks before virus inoculation

X-ray irradiation, 1500 r

Virus inoculated 2 days after last treatments

TABLE III

*Susceptibility of Normal Skin and Skin Treated with Ultraviolet Light, Turpentine and Acetone, and Methylcholanthrene*

Dilution of virus filtrate (R. 1:30)	Skin treatment before virus inoculation*	Pathogenicity tests											
		11th day				18th day				35th day			
		a	b	c	d	a	b	c	d	a	b	c	d
1st rabbits													
per cent													
0.1	Normal skin	0	0	0	0	±	±	+	±	++	+++	++	+++
	Ultraviolet light	0	0	0	0	±	±	+	+	+++	+++	++	+++
	Turpentine-acetone	±	+	0	±	+++	+++	++	+++	++++	++++	++++	+++
	Methylcholanthrene	0	±	+	0	+++	+++	+++	+++	++++	++++	++++	+++
5	Normal skin	0	++	+	+	+++	+++	+++	+++	++++	++++	++++	+++
	Ultraviolet light	+	+++	++	++	+++	+++	+++	+++	++++	++++	++++	+++
	Turpentine-acetone	±	+++	+++	+++	+++	+++	+++	+++	++++	++++	++++	+++
	Methylcholanthrene	±	+++	+++	+++	+++	+++	+++	+++	++++	++++	++++	+++

\* Ultraviolet light, 40 minutes irradiation from a carbon lamp 24 hours before virus inoculation

Turpentine and acetone in equal parts applied to skin five times at 2 day intervals

0.3 per cent methylcholanthrene in benzene applied to skin five times at 2 day intervals

greater numbers than on those which had been normal. There was no significant difference between the growths on the treated areas and they all soon became large, confluent papillomatous masses. The papillomas arising on the areas which had been exposed to ultraviolet light were like those on the normal skin in number and size.

The results of Experiments 2, 3, and 4 (Tables I, II, and III) show that a variety of agents, some carcinogenic, others not, will render the skin abnormally susceptible to virus infection. A mixture of turpentine and acetone was as effective in this respect as was tar or methylcholanthrene. These findings have been confirmed in many subsequent tests in which the procedures have been utilized for various purposes. Mere acute inflammation produced by ultraviolet light did not render the skin more susceptible, nor did the Roentgen rays.

#### *Optimal Preparation of the Skin for Virus Infection*

Steps were now taken to determine the number of applications of methylcholanthrene or of turpentine and acetone which renders the skin most susceptible to the papilloma virus.

*Experiment 5*—0.3 per cent methylcholanthrene in benzene was painted onto a skin area of each of four domestic rabbits at 2 day intervals for a total of six times, and another comparable skin area was simultaneously treated with a mixture of turpentine and acetone. Two other skin areas of the same animals were treated with the agents three times at 2 day intervals, while another two areas received but a single application. The schedule was so arranged that the last application was made 24 hours prior to virus inoculation. Two skin areas on each rabbit were left untreated. As usual the situation of the treated areas was varied. A single application of methylcholanthrene caused only a reddening of the skin after 24 hours. After three applications however the skin was acutely inflamed, thickened, and covered with a branny scurf. Six treatments caused even greater changes with marked thickening and much scurf, some of which could be flaked away. Turpentine and acetone caused similar changes, but the skin was slightly less thickened, although more inflamed. Biopsy specimens were taken from all of the areas. Immediately afterward the areas were scarified and a 0.5 per cent virus extract (W.R. 128) was rubbed into them.

The results are summarized in Table IV. It will be seen that a single application of methylcholanthrene or turpentine and acetone did not alter the susceptibility of the skin to papilloma virus infection, the incubation period and the number and size of growths were about the same on the normal and treated skin areas. Those treated three times, however, showed numerous papillomas before any could be seen on the normal areas and they had become large, confluent masses, up to 1.6 cm. high at a time when growths on the normal skin were still discrete or semiconfluent and no more than 0.4 cm. high at most. Six applications of the agents rendered the skin only slightly more susceptible to virus infection than did three applications, in spite of the fact that it appeared much more changed, and histologically was really so, as will be shown further on.

Six applications of methylcholanthrene or turpentine and acetone at 2 day intervals are about the maximum that the skin of the rabbit's abdomen will bear without becoming macerated<sup>3</sup>. It will withstand many applications of methylcholanthrene, however, if applied at 3 to 4 day intervals. Further experiments have shown that many treatments with these agents fail to render the epidermis more susceptible than do three to six applications at 2 day intervals.

TABLE IV  
*Susceptibility of Skin Prepared for Various Lengths of Time*

Agent applied to skin before virus inoculation*	No. of applications	Pathogenicity tests†											
		12th day				16th day				24th day			
Test rabbits		a	b	c	d	a	b	c	d	a	b	c	d
Normal skin		0	0	0	0	+	±	±	++	+++	+++	++	+++
Turpentine acetone	One	0	0	0	0	++	+	+	+	++++±	+++±	++	+++
	Three	±	±	±	++	+++	+++	+++	+++	+++++	+++++	+++++	+++++
	Six	+	+++	+++	+	+++	+++±	+++±	+++	+++++	+++++	+++++	+++++
Methylcholanthrene	One	0	0	0	0	+	±	±	±	+++	++	++	+++
	Three	±	±	+	++	++	+++	+++	+++	+++++	+++++	+++++	+++++
	Six	±	++	+++	++	+++	+++±	+++	+++	+++++	+++++	+++++	+++++

\* Turpentine and acetone in equal parts

Methylcholanthrene, 0.3 per cent in benzene

† Virus extract, W R 1-28, 0.5 per cent, rubbed into scarified skin 24 hours after preparation

### *Duration of the Abnormal Susceptibility*

Does the increased susceptibility of methylcholanthrene-treated skin to papilloma virus infection persist when applications of methylcholanthrene are discontinued? To answer this question skin areas were treated with methylcholanthrene in the next experiment and then inoculated with papilloma virus at various intervals from 1 day to 1 month after completion of the treatments.

*Experiment 6*—Five areas on each of five rabbits were painted with 0.3 per cent methylcholanthrene in benzene at intervals of 2 days for a total of four times. The treatment of each skin area was begun on a different date so that from 24 hours to 4

<sup>3</sup> The agents mentioned induce a profuse growth of hair. It has been found that removal of this with clippers prior to each application provides a better prepared epidermis which can be readily scarified.

weeks had elapsed on the day when they were all inoculated with 0.1 per cent virus filtrate (W.R. E). Just prior to inoculation biopsies were made as usual.

Table V shows the results of the Experiment. As noted in the preceding tests, papillomas appeared earlier and in greater number on the methylcholanthrene-treated skin inoculated 24 hours after completion of the treatments than on scarified normal skin. The areas inoculated with virus 1 week afterwards showed slightly fewer papillomas in four of the five test rabbits but in one instance there was no difference. The skin inoculated 3 weeks after discontinuation of the methylcholanthrene applications showed more growths than the normal skin in two instances only, and the patches inoculated 4 weeks after the applications had been stopped yielded the same results as the normal

TABLE V  
*Duration of the Increased Susceptibility of Methylcholanthrene Treated Skin*

Time from skin treatment* to virus inoculation†	Pathogenicity tests														
	14th day					16th day					21st day				
	a	b	c	d	e	a	b	c	d	e	a	b	c	d	e
Test rabbits															
1 day	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1 wk.	±	±	±	±	±	±	±	±	±	±	±	±	±	±	±
2 wks.	±	+	0	+	+	±	±	±	±	±	±	±	±	±	±
3 wks.	0	0	0	±	±	±	±	±	±	±	+	±	+	±	±
4 wks.	0	0	0	0	0	+	±	±	±	±	+	+	±	±	±
Normal skin	0	0	0	0	0	+	±	±	+	±	±	+	±	±	+

\* 0.3 per cent methylcholanthrene in benzene applied to skin four times at 2 day intervals.

† Virus filtrate, W.R. E, 1:1000

skin. It is thus apparent that the increased reactivity of methylcholanthrene treated skin to papilloma virus infection is transitory and is lost within 2 to 4 weeks after the treatments are stopped.

#### *Comparative Titrations of the Virus on Normal and Altered Skin*

The increased number, shortened incubation period, and the rapidity with which the papillomas enlarged when virus was inoculated into properly prepared skin pointed to a markedly increased effectiveness of the virus. Experiments were next undertaken to learn whether it would be infectious in dilutions which yield no growths under ordinary circumstances. The virus is rarely infectious on the scarified normal skin of domestic rabbits in dilutions beyond 1:100,000 (in terms of weight of papilloma tissue extracted) (6).

*Experiment 7*—Six squares were clipped on one side of the belly of four rabbits, and painted with a mixture of turpentine and acetone five times at 2 day intervals. They



showed the usual alterations. Six corresponding squares on the other side were not treated. All were scarified and a papilloma virus extract (W R 1-28) in dilutions of from 1 10,000 to 1 10,000,000 was rubbed into corresponding normal and treated squares. The inoculations were made 24 hours after the last of the turpentine acetone applications.

It will be seen (Table VI) that by the 16th day after inoculation all of the treated areas which had received the 1 50,000 dilution of virus showed papillomas and the 1 100,000 had also caused them in one animal. No growths whatever had appeared at this time on the control squares. Later the control areas showed papillomas in every case as result of the 1 50,000 dilution, and the 1 100,000 dilution also caused them in the more susceptible animals. But

TABLE VI

*Titration of a Virus Preparation in Normal and in Turpentine and Acetone Treated Skin*

Dilution of virus extract W.R. 1/28	Pathogenicity tests															
	16th day								42nd day							
	Normal skin				Turpentine and acetone treated skin*				Normal skin				Turpentine and acetone treated skin*			
Test rabbits	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
1/10 000	0	0	0	0	+	+	++	++	++++	++++	+++	+++	++++	++++	++++	++++
1/50 000	0	0	0	0	±	±	±	±	+	+++	+	±	++++	++++	++++	+++
1/100 000	0	0	0	0	0	±	0	0	±	+++	±	0	++++	++++	++	+
1/500 000	0	0	0	0	0	0	0	0	0	0	0	0	+	++	++	±
1/1 000 000	0	0	0	0	0	0	0	0	0	0	0	0	±	+	±	0
1/10 000 000	0	0	0	0	0	0	0	0	0	0	0	0	0	±	0	0

\* Turpentine and acetone in equal parts applied three times per week for a total of five times before virus inoculation.

the virus had proved greatly more effective on the treated areas. At 1 100,000 it regularly produced papillomas, as did the 1 500,000 dilution, while in three of the four animals the 1 1,000,000 dilution proved effective, and in one individual the virus extract yielded papillomas when diluted 10,000,000 times.

The experiment shows that not only was the number of papillomas increased and the incubation period shortened by the use of treated skin but the titer of the virus was much stepped up—from 10- to 100-fold. Another, similar experiment, using methylcholanthrene-treated skin and another virus extract, yielded practically identical results. In a subsequent paper many instances will be given, incidentally to other work, of the enhanced susceptibility of treated skin.

#### *Effect of Skin Alterations before and after Virus Inoculation*

It seemed possible that methylcholanthrene or turpentine and acetone applications to the epidermis after virus inoculation might have the same

effect as preliminary treatment. An experiment was done to test the possibility

*Experiment 8*—Nine areas in three parallel rows were clipped on the abdomens of four rabbits. Those of one row were painted with 0.3 per cent methylcholanthrene in benzene at 2 day intervals for a total of four times, with result in the usual changes. The other six patches were not treated. Two days after the last treatment all were scarified and inoculated with a virus extract (W.R. 295) in dilutions of 1:50,000,

TABLE VII

*Infectivity of Virus in Skin Treated with Methylcholanthrene before and after Inoculation*

Skin treatment	Dilution of virus extract W.R. 295 used for inoculation	Pathogenicity tests											
		18th day				28th day				35th day			
Test rabbits		a	b	c	d	a	b	c	d	a	b	c	d
Methylcholanthrene applied to skin four times before inoculation	1:50,000	++	++	++	++	+++	+++	+++	+++	+++	+++	+++	+++
	1:500,000	±	+	±	+	++	++	+	++	++	++	+	++
	1:5,000,000	0	±	0	0	+	+	±	±	++	±	±	±
Methylcholanthrene applied to skin four times after virus inoculation	1:50,000	±	0	0	±	±	+	0	±	±	+	0	±
	1:500,000	0	0	0	0	0	0	0	0	0	0	0	0
	1:5,000,000	0	0	0	0	0	0	0	0	0	0	0	0
Normal skin	1:50,000	±	0	0	0	++	+	±	0	++	+	±	0
	1:500,000	0	0	0	0	±	0	0	0	±	0	0	0
	1:5,000,000	0	0	0	0	0	0	0	0	0	0	0	0

\* 0.3 per cent methylcholanthrene in benzene applied to skin four times at 2 day intervals before virus inoculation

† 0.3 per cent methylcholanthrene in benzene applied to skin four times at 2 day intervals beginning 5 days after virus inoculation

1:500,000, and 1:5,000,000. One area of each row received the same dilution of virus. Five days later, when the skin areas had almost healed, one of the rows of patches which had not been treated prior to inoculation was painted with 0.3 per cent methylcholanthrene in benzene and the applications were kept up at 2 day intervals for a total of four times, again inducing the familiar changes. To the other rows of patches nothing further was done.

The results of the experiment are set down in Table VII. On the 18th day after inoculation the virus diluted 1:500,000 had caused papillomas on all of the patches treated with methylcholanthrene prior to inoculation and so too had a dilution of 1:5,000,000 in one rabbit. The control patches and those treated with methylcholanthrene after inoculation showed at this time no

papillomas where virus had been inoculated in dilutions above 1 50,000, and they were only just appearing where this latter had been put. By the 35th day (after which no growths appeared) the 1 5,000,000 dilution of the virus had produced papillomas on all of the skin areas treated before inoculation, but had failed to cause growths on untreated areas or on those that were treated with methylcholanthrene after virus inoculation. 1 50,000 caused large, confluent or semiconfluent papillomatous masses on all of the areas prepared before inoculation, but it produced only a few discrete growths on the other areas.

Manifestly, methylcholanthrene treatment of the skin after virus inoculation did not enhance the effects of the virus. A similar experiment, using a mixture of turpentine and acetone instead of methylcholanthrene, yielded similar results except that fewer growths arose on the skin treated with the turpentine and acetone after scarification than on the untreated skin.

### *Results of Altering the Skin of Cottontail Rabbits*

The work was now extended to cottontail rabbits, the natural hosts of the papilloma virus, to learn whether their skin can be rendered more susceptible to the virus.<sup>4</sup>

Several experiments of the sort already described were frustrated by skin injury, maceration and bacterial infection occurring when two to four applications of methylcholanthrene or the mixture of turpentine and acetone were applied at 2 day intervals, —procedures well tolerated in the domestic rabbit. However, when the intervals were lengthened to 4 days the skin underwent the same gross changes as in these latter animals. But unfortunately it also became notably susceptible to bacterial infection and scarification frequently resulted in broad abscesses. To avoid these, resort was had to intradermal inoculations of the virus. These gave irregular results, yet by and large the several experiments gave clear indications that methylcholanthrene, benzene, and a mixture of turpentine and acetone, all render the epidermis of the cottontail rabbit unusually susceptible to the papilloma virus.

### *Nature of the Skin Changes*

The agents that enhanced the susceptibility of the skin for the papilloma virus all caused marked alterations of the same general sort. In the gross they consisted of thickening, scurfing, increased pigmentation, and more or less

<sup>4</sup> The papilloma virus ordinarily titers slightly higher in susceptible cottontails than in the domestic species. Table VIII shows the results of rubbing graded dilutions of a virus extract (WR 1-28) into scarified skin areas of six normal domestic rabbits and six cottontail rabbits. One cottontail proved immune to the virus and hence was not included in the table. It will be seen that the virus extract produced growths in all of the cottontail rabbits in dilutions up to 1 800,000, whereas this last caused none in any of the domestic rabbits, and in only two of the six did a dilution of 1 400,000 cause any.

acute inflammation. The extent of the changes, however, varied with the agent used.

The microscopic findings can be briefly summarized —

The normal skin of the abdomen of the domestic rabbit has a thick connective tissue stroma and a mere skim of superficial epidermis (Fig 1), consisting of a Malpighian layer one to three cells thick which keratinizes abruptly without differentiation. The hair follicles do not go deep and the sebaceous glands are small and inconspicuous. Three to four applications of tar to the skin were found to cause striking changes (Fig 2). The Malpighian layer became greatly thickened and the cells appeared larger than normal and showed many mitoses. They differentiated gradually forming a granular layer and a thick stratum of keratinization. The hair follicles became greatly distended with keratin in many instances. Numerous sebaceous glands appeared and the dermis showed an acute inflammatory reaction with edema, small hemorrhages, and cellular infiltration. All these changes have been often described before. A single application of methylcholanthrene caused a mild inflammatory reaction in the dermis and the basal cells of the epidermis appeared to be slightly larger than normal but were not increased in number. After three or four applications the epidermis was markedly hyperplastic and the changes were similar to those seen in the tarred skin, but lesser in degree (Fig 8). After six applications there was even greater thickening and irregularity of the epidermis and portions of the skin were necrotic. When the treatments were discontinued the skin gradually reverted to the normal. Within 1 week after the skin had received four applications of methylcholanthrene, regression was evident. The epidermis was still thicker than normal and exhibited a graded differentiation but the cells showed far fewer mitoses than 24 hours after the treatments and were smaller and less abnormal. Within 2 weeks involution was advanced, and after 3 weeks the epidermis had returned to normal save for a slight hyperkeratosis. The hair follicles appeared normal now except at the bases where there was still some thickening of the epithelial layer and the cells showed numerous mitoses and were slightly larger than normal. A few polymorphonuclear leucocytes could still be seen in the connective tissue. After 4 weeks the skin seemed wholly normal. Benzopyrene caused changes similar to those induced by methylcholanthrene except that the sebaceous glands were more hyperplastic and occasionally cystic.

The non-carcinogenic agents which were effective in increasing the susceptibility of the skin for the virus brought about much the same histological changes. Turpentine and acetone caused less hyperplasia of the epidermis than methylcholanthrene (Fig 3) but a more acute inflammatory reaction in the subcutaneous tissue. The benzene-treated skin was less hyperplastic than that altered by methylcholanthrene but the general changes were similar. Occasionally there were small patches of epidermal necrosis. The sebaceous glands were markedly hyperplastic and showed differentiation.

Ultraviolet light caused an acute inflammatory reaction 48 hours after irradiation, but the epidermis was still as thin as usual at this time and sometimes showed small areas of necrosis. X-ray irradiation elicited no significant changes in the skin under the conditions employed (Experiment 3). These agents failed to alter the susceptibility of the skin for the virus as Experiments 3 and 4 showed.

The microscopic changes elicited in cottontail rabbit skin by the carcinogenic and non-carcinogenic agents were at least as marked as those seen in the domestic rabbit and usually more so. Two to three applications of methylcholanthrene, benzene, or turpentine and acetone at intervals of 4 days changed the epidermis of the wild rabbit from a thin, delicate epithelium one to two cells thick, to a greatly thickened and irregular, differentiating sheet, with distended, hyperplastic hair follicles and numerous sebaceous glands. Further applications usually rendered the epidermis necrotic.

The findings plainly showed that the various agents which enhanced the susceptibility of rabbit skin all caused the epidermis to become hyperplastic and to proliferate actively. The agents which proved ineffective,—ultraviolet light and x-ray,—did not do so, although the former produced an acute inflammatory reaction in the skin.

### *The Skin Changes Induced by Scarification*

Several authors have described the early stages in virus-induced papillomatosis (9) but no one has inquired into the changes which follow immediately upon scarification of the skin and virus inoculation. It seemed probable that a knowledge of these changes would aid toward an understanding of the reasons for the increased susceptibility of altered skin, and consequently a study of them was undertaken. Papilloma virus was rubbed into some scarified areas and a solution of minute graphite particles (hydrokollag (10)) into others, to learn the fate of particulate matter as such.

*Experiment 9*—Nine skin areas on the abdomens of three domestic rabbits were painted with 0.3 per cent methylcholanthrene in benzene at 2 day intervals for a total of four times. 24 hours after the last treatment a representative piece of the changed skin was removed from each animal. All of the areas were then scarified with sand paper to the usual extent, that is to say, until there was oozing of serum, sometimes blood-tinged, and a 5 per cent papilloma virus extract (W. R. D.) was rubbed into three of the patches, a dilute suspension of hydrokollag in saline into three others, while the remaining three areas were left as such. In addition nine untreated areas on each of three other rabbits were similarly scarified and the virus and the hydrokollag suspension were rubbed into them. Slices of skin were taken from all of the various areas 5 hours after scarification, and additional pieces were procured after 1, 2, 4, 6, 8, 11, and 14 days. They were fixed in acid Zenker's and stained with eosin and methylene blue. Duplicate sections from the areas receiving hydrokollag were stained with Lichtgrün as well.

It was found that scarification of the *normal skin* to the extent ordinarily employed for virus inoculation removed practically all of the epithelial covering and some of the superficial connective tissue as well, cutting across the hair follicle shafts near the surface. Only occasional small islands of surface epidermis were left. After 24 hours the connective tissue was edematous and showed a few polymorphonuclear leucocytes and a thin scab had formed on the surface, but as yet no epithelial repair had taken place. The scab had become much thicker after 24 hours, owing not only to the ac-

cumulation of dried exudate but mostly to necrosis of the superficial connective tissue layer with incorporation of the dead material in the scab. After 48 hours epithelial regeneration was for the first time plainly evident. It took origin almost entirely from the cells of the hair follicle shafts, the epithelial cells extending laterally between scab and living connective tissue and sometimes into crevices in the latter. The first extension seemed to be mostly migration though occasional mitoses could be seen. The newly formed cells showed many mitoses later. After 2 to 4 days they had multiplied and spread laterally to such extent as to form umbrella like expanses with the hair follicles as the shafts of the umbrellas. At this time the epidermis had not nearly covered all of the denuded surface. The connective tissue was still edematous and showed some round cells and polymorphonuclear leucocytes but the scab had begun to separate here and there. After 4 to 8 days the surface was entirely covered with a layer of hyperplastic epithelium (Fig. 5) three to six cells thick which had differentiated into granular and keratinized layers. The picture was markedly different from the normal (Fig. 1). The hair follicle shafts had thickened only slightly except next the orifices where the epithelium was hyperplastic. There was no evident stimulation of the sebaceous glands. At this time the surface scab had only just come away and remnants of it could be seen. Later the hyperplastic epidermis slowly took on a normal appearance and by the 14th day it had nearly done so though here and there it was still slightly thickened and hyperkeratotic.

*The skin areas inoculated with papilloma virus* showed similar general changes during the first days, and with the inoculum employed—which gave rise to growths relatively late,—changes referable to the virus were not discerned until 6 to 8 days had elapsed. Then the characteristic alterations of early papillomatosis (9) could be made out here and there. By the 11th to the 14th day there were discrete characteristic growths. The microscope showed most of them to have arisen from the basal layers of the new hyperplastic epidermis which now covered the surface between the hair follicles.

*The areas into which hydrokollag had been rubbed* showed the black particles in close contact with the abraded surface immediately after the incision and in direct contact with the epithelium of the hair follicles that had been cut across. But as the scab thickened owing to the necrosis of the superficial tissue with incorporation in it of the dead layer almost all of the hydrokollag became incorporated too, only traces remaining in crevices here and there where it might come in contact later with the regenerating epithelial cells. Careful search was made for phagocytosis of it by these elements but none could be found, and when the newly formed epidermis keratinized, by the 4th to the 8th day after scarification, it was all cast off.

These findings show that the scarification of normal skin as ordinarily done removes nearly all of the surface epidermal cells and entails a loss of most of the virus (if one can judge from what happens to hydrokollag) in the scab which forms, the result being that the chance for it to reach susceptible cells is greatly reduced. Almost the only spots at which virus is directly brought into contact with epithelium are where the hair follicles have been cut across and even here the epithelium commonly becomes implicated in the later

necrosis and is lost. Papillomas derived from the hair follicle epithelium are relatively infrequent. Instead they usually appear on the surface between the hair follicles and one must suppose they principally arise from young, regenerating cells which have extended laterally from the follicles to cover the denuded surface.

Scarification of the *methylcholanthrene-treated skin* (Fig 8) was done to the same extent as with normal skin, that is to say, until the surface of the patch seemed everywhere abraded and serum oozed out. Though the surface epithelium was markedly hyperplastic, the microscope showed that practically all of it had been removed as in the case of the normal skin, exposing the fibrous corium and the hair follicle shafts (Fig 9). These latter were hyperplastic. The connective tissue became edematous as usual, polymorphonuclear leucocytes wandered into it, and scabbing took place with increase in the thickness of the scab by superficial necrosis (Fig 10). But epithelial regeneration was far more rapid than under ordinary circumstances. Within 24 hours after scarification it was already far advanced (Fig 10) and within 48 hours the entire abraded surface was covered (Fig 11). Migration began by lateral extension from the hair follicles, and was attended by such active multiplication that very soon large, thick, umbrella-like structures with the follicles as the shafts of the umbrellas had formed beneath the surface scab (Fig 12). They consisted of great numbers of epidermal cells, many of them in mitotic division, and as these spread along the surface beneath the scab they frequently invaded irregularly the crevices in the fibrous corium. The sheet of hyperplastic, actively regenerating epidermis that rapidly formed was much thicker than that produced by the regeneration of ordinary epidermis (Fig 5) and consisted of a shallow keratinized layer and a Malpighian layer ten to fifteen cells deep, showing numerous mitoses. Irregular papillae extended down into the connective tissue. The hair follicles were distended with keratinized epithelium and the epithelial lining was thickened. There appeared to be a notable increase in the number of sebaceous glands and they were rendered prominent not only by hyperplasia but by retention of secretion which caused many of them to be actually cystic. It seems probable that the hyperplastic surface epithelium had become so crowded through active proliferation as to prevent escape of their contents. Four to 6 days after scarification the epidermis was more orderly, differentiating into wide granular and keratinized layers, and as keratinization progressed the scab came away. Involution took place rapidly and by the 14th day the epithelium had returned practically to normal save for irregularities of basal contour and local thickenings where the layer of living cells was still three to four cells deep. The hyperkeratosis was now in general less than that where the normal skin had been scarified 14 days previously. While involution was going on the sebaceous glands at first became still more cystic, some of them rounding out into small spheres but later the distention of them disappeared and they again became inconspicuous.

The *methylcholanthrene treated areas which were inoculated with virus* after scarification underwent similar changes. The effects of the virus were evident in them earlier than when scarified normal skin had received the same inoculum, the characteristic cytological changes indicative of the beginning of papillomatosis being perceptible in one rabbit 4 days after inoculation and on the 6th day in others. The fate of the

hydrokollag was the same as when rubbed into scarified normal skin. Practically all of it was caught in the scab and came away when this did

From these findings it is plain that the changes which render skin especially susceptible to the virus provide to the latter young, actively proliferating epidermal cells in unusually great number and at a much earlier stage in events than when normal skin has been scarified. Where the hair follicles have been cut across by the sandpaper many more cells are exposed to direct infection with the virus, and where it persists under the scab the regenerating epithelium soon reaches it.

### *Intradermal Inoculation of Virus into Prepared Rabbit Skin*

Despite the defects of inoculation into scarified areas as just disclosed, it has proved the most certain method to the present for titrating the papilloma virus. Intradermal injection of active virus into normal skin does not always result in growths, and the incubation period is regularly longer than in scarified skin (4)\*. It has seemed worth while nevertheless to determine the effects of the intradermal inoculation of virus in skin altered by methylcholanthrene. Accordingly papilloma virus was so inoculated and was also rubbed into scarified normal and methylcholanthrene treated skin areas at comparable situations in the same animals. Incidentally, to enlarge the general findings, a mixture of methylcholanthrene and Scharlach R was applied to some areas, and the dye was injected intradermally into other areas that had also been treated with methylcholanthrene prior to virus inoculation. Scharlach R is known to cause a profuse epidermal proliferation and sometimes temporary downgrowths simulating early carcinomatosis (11).

*Experiment 10*—Four rectangular areas were clipped on each side of the abdomens of four rabbits. One on each side was painted with 0.3 per cent methylcholanthrene in benzene, another with a saturated solution of Scharlach R in benzene containing 0.3 per cent methylcholanthrene, while a third was painted with 0.3 per cent methylcholanthrene in benzene and 0.1 to 0.2 cc. of a saturated solution of Scharlach R in olive oil was injected intradermally at several places. The treatments were repeated four times at 2 day intervals. The fourth area on each side served as control. Two days after the last treatments pieces were taken from each area of two of the rabbits for microscopic study. The mixture of methylcholanthrene and Scharlach R caused much greater skin alterations than did methylcholanthrene alone. The thickened skin was rendered far more rugose and became so redundant as to be thrown into folds. Microscopically, the changes resembled in many ways those seen in the tarred epidermis, already described, but the thickening of the surface layer of epithelium

\* This is also true of tattoo inoculations.



virus, herpes virus, and virus III is found in the young cells filling in the defects consequent on scarification (13)

The experiments here reported to learn the effects of the scarification preliminary to virus inoculation and the stages in its repair have disclosed that most of the surface epithelium is scraped away and that practically all of what is left, and the superficial connective tissue as well, is destroyed in the scab which forms within the next 2 days. As already pointed out, the virus rubbed into the raw surface must also be lost in the scabbing and but little can remain here or there underneath the dead material to infect the young, regenerating epidermal cells which extend from the hair follicles. It is possible that some direct infection of the preexisting hair follicle cells may occur at the time when the shafts of the follicles are cut across by the sandpaper and the virus is rubbed in, but this seems unlikely because the scabbing involves them too. Indeed, microscopically one seldom sees papillomas beginning at the hair follicles, these ordinarily arising from the reconstituted surface sheet of epithelium which lies between them.

The various agents which render the skin more susceptible to infection with the virus all effect changes which should bring young, actively regenerating cells into association with the virus in much greater number than ordinary and at a much earlier time. They also increase the local vascularity, and to this circumstance as well as to a much more abundant initial cell infection the shortened incubation period and subsequent rapid enlargement of the papillomas can be laid. Olitsky and Schlesinger (14) have recently shown that local edema produced by the subcutaneous injection of hypertonic solutions prior to inoculation of the skin with herpes virus greatly increases the effectiveness of the latter, and Sprunt (15) has brought evidence to show that susceptibility to infection with vaccine virus is influenced by the number of cells exposed to the latter. But the increased susceptibility of the altered skin for papilloma virus may be due to more than the provision of a richer vascularization and of an increased number of susceptible cells for infection. The individual young cells of an epidermis regenerating after alteration by the preparatives of the present work may be especially susceptible to the virus.

Under the ordinary circumstances of scarification and virus inoculation infection takes place at scattered points with secondary coalescence, the result being separate more or less broad-based papillomas or confluent papillomatous expanses. The scattered character of the initial infection explains why confluent masses usually have craggy peaks with clefts between that frequently extend down to the skin level, and why on cross-section local differences can be perceived, which are expressions of the proliferation of differing infected cell families (16). Only occasionally does infection by scarification result in growths so compacted as to suggest that a broadcast, primary infection has

taken place. Naturally occurring papillomas in cottontails are not infrequently compacted, however, having the form of solid discs or "onions," presumably because they are the outcome of primary punctate infection with expansile enlargement. Growths of similar sort can be produced experimentally in both cottontails and domestic rabbits by intradermal or tattoo inoculation.

Bryan and Beard (17) have lately laid stress on the length of the incubation period (time elapsing after inoculation before papillomas are visible in the gross) as a reliable indicator of the amount of active virus present in the inoculum. There can, of course, be no doubt that the greater the number of virus entities distributed upon a scarified area the greater the chance will be for cells to become infected, up to a certain maximum, other things being equal and,—since most papillomas are consequent on multiple cell infection,—the sooner should the papillomas appear. But if the skin is abnormal other factors enter into the matter, as the present work shows, notably the regenerative activities of the epidermis and the local vascular state. The rate of appearance of papillomas is conditioned not only by virus quantity and pathogenicity but by the state of the tissue acted upon.

The experiments here reported provide a practicable method to render papilloma virus many times more effective on experimental inoculation. Papilloma extracts that do not elicit growths in normal skin in dilutions beyond 1:100,000 produce growths in methylcholanthrene- or turpentine and acetone-treated skin in dilutions of 1:1,000,000 or 1:10,000,000, while furthermore the incubation period of the papillomas in the altered skin is considerably shorter than in normal skin. It has been calculated that about 94,000,000 papilloma protein molecules are present in the dilution giving the 50 per cent point (18). The findings of the present experiments suggest that this figure mostly expresses the difficulty of bringing virus into association with susceptible cells. By the means described in the present work the number of entities in the inoculum requisite to infection can be reduced considerably, although under the circumstances of virus inoculation into scarified skin most of the virus is still lost by the way. To gauge the effectiveness of individual papilloma virus entities one would have to be certain that these reached the appropriate cells and that the latter were in a state to be infected. Needless to say, these considerations apply to other viruses as well.

Experiments carried out with Dr. John G. Kidd have shown that skin preparation by the methods here described is useful in demonstrating papilloma virus in materials which fail to give rise to growths when inoculated in the ordinary way. Extracts of domestic rabbit papillomas which are non-pathogenic when so tested, in which, that is to say, the virus appears to be "masked," produce growths in most instances when inoculated into methylcholanthrene-

virus, herpes virus, and virus III is found in the young cells filling in the defects consequent on scarification (13)

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taken place. Naturally occurring papillomas in cottontails are not infrequently compacted, however, having the form of solid discs or "onions," presumably because they are the outcome of primary punctate infection with expansile enlargement. Growths of similar sort can be produced experimentally in both cottontails and domestic rabbits by intradermal or tattoo inoculation.

Bryan and Beard (17) have lately laid stress on the length of the incubation period (time elapsing after inoculation before papillomas are visible in the gross) as a reliable indicator of the amount of active virus present in the inoculum. There can, of course, be no doubt that the greater the number of virus entities distributed upon a scarified area the greater the chance will be for cells to become infected, up to a certain maximum, other things being equal and,—since most papillomas are consequent on multiple cell infection,—the sooner should the papillomas appear. But if the skin is abnormal other factors enter into the matter, as the present work shows, notably the regenerative activities of the epidermis and the local vascular state. The rate of appearance of papillomas is conditioned not only by virus quantity and pathogenicity but by the state of the tissue acted upon.

The experiments here reported provide a practicable method to render papilloma virus many times more effective on experimental inoculation. Papilloma extracts that do not elicit growths in normal skin in dilutions beyond 1:100,000 produce growths in methylcholanthrene- or turpentine and acetone-treated skin in dilutions of 1:1,000,000 or 1:10,000,000, while furthermore the incubation period of the papillomas in the altered skin is considerably shorter than in normal skin. It has been calculated that about 94,000,000 papilloma protein molecules are present in the dilution giving the 50 per cent point (18). The findings of the present experiments suggest that this figure mostly expresses the difficulty of bringing virus into association with susceptible cells. By the means described in the present work the number of entities in the inoculum requisite to infection can be reduced considerably, although under the circumstances of virus inoculation into scarified skin most of the virus is still lost by the way. To gauge the effectiveness of individual papilloma virus entities one would have to be certain that these reached the appropriate cells and that the latter were in a state to be infected. Needless to say, these considerations apply to other viruses as well.

Experiments carried out with Dr. John G. Kidd have shown that skin preparation by the methods here described is useful in demonstrating papilloma virus in materials which fail to give rise to growths when inoculated in the ordinary way. Extracts of domestic rabbit papillomas which are non-pathogenic when so tested, in which, that is to say, the virus appears to be "masked," produce growths in most instances when inoculated into methylcholanthrene-

virus herpes virus, and virus III is found in the young cells filling in the defects consequent on scarification (13)

The experiments here reported to learn the effects of the scarification preliminary to virus inoculation and the stages in its repair have disclosed that most of the surface epithelium is scraped away and that practically all of what is left, and the superficial connective tissue as well, is destroyed in the scab which forms within the next 2 days. As already pointed out, the virus rubbed into the raw surface must also be lost in the scabbing and but little can remain here or there underneath the dead material to infect the young, regenerating epidermal cells which extend from the hair follicles. It is possible that some direct infection of the preexisting hair follicle cells may occur at the time when the shafts of the follicles are cut across by the sandpaper and the virus is rubbed in, but this seems unlikely because the scabbing involves them too. Indeed, microscopically one seldom sees papillomas beginning at the hair follicles, these ordinarily arising from the reconstituted surface sheet of epithelium which lies between them.

The various agents which render the skin more susceptible to infection with the virus all effect changes which should bring young, actively regenerating cells into association with the virus in much greater number than ordinary and at a much earlier time. They also increase the local vascularity, and to this circumstance as well as to a much more abundant initial cell infection the shortened incubation period and subsequent rapid enlargement of the papillomas can be laid. Olitsky and Schlesinger (14) have recently shown that local edema produced by the subcutaneous injection of hypertonic solutions prior to inoculation of the skin with herpes virus greatly increases the effectiveness of the latter, and Sprunt (15) has brought evidence to show that susceptibility to infection with vaccine virus is influenced by the number of cells exposed to the latter. But the increased susceptibility of the altered skin for papilloma virus may be due to more than the provision of a richer vascularization and of an increased number of susceptible cells for infection. The individual young cells of an epidermis regenerating after alteration by the preparatives of the present work may be especially susceptible to the virus.

Under the ordinary circumstances of scarification and virus inoculation infection takes place at scattered points with secondary coalescence, the result being separate more or less broad-based papillomas or confluent papillomatous expanses. The scattered character of the initial infection explains why confluent masses usually have craggy peaks with clefts between that frequently extend down to the skin level, and why on cross-section local differences can be perceived which are expressions of the proliferation of differing infected cell families (16). Only occasionally does infection by scarification result in growth so compacted as to suggest that a broadcast, primary infection has

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or turpentine and acetone-treated skin. These findings will be reported in detail in a forthcoming paper.

### SUMMARY

Rabbit skin can be rendered abnormally susceptible to papilloma virus infection by preliminary treatments with a variety of agents. The most effective agents thus far found are 0.3 per cent methylcholanthrene in benzene and a mixture in equal parts of turpentine and acetone, applied four or five times at 2 day intervals. When virus is inoculated into skin altered by these agents, either intradermally or by inoculation after scarification, papillomas appear earlier and in greater number than on normal skin, and much higher dilutions give rise to growths. The method provides a means of detecting amounts of virus which cause no papillomas upon inoculation into normal skin.

Papilloma virus material which is rubbed into scarified normal or hyperplastic skin is largely lost in the scabbing which ensues, and nearly all of it fails to reach susceptible cells. The preparatory agents which increase the effectiveness of the virus bring about marked epidermal hyperplasia, and the hyperplastic tissue regenerates with greater rapidity when scarified. The agents evidently act in large part by providing young epidermal cells in quantity to the virus, as also by inducing a richer vascularization than ordinary in support of the papillomatous proliferation. It is possible that they also act by providing especially susceptible cells. The implications of the findings are discussed.

### BIBLIOGRAPHY

- 1 Teague, O., and Goodpasture, E. W., *J. Med. Research*, 1923-24, 44, 185
- 2 Rivers, T. M., Stevens, H., and Gates, F. L., *J. Exp. Med.*, 1928, 47, 37
- 3 Shope, R. E., *J. Exp. Med.*, 1933, 58, 607
- 4 Rous, P., and Kidd, J. G., *J. Exp. Med.*, 1938, 67, 399, 68, 529
- 5 Kidd, J. G., Beard, J. W., and Rous, P., *J. Exp. Med.*, 1936, 64, 63
- 6 Kidd, J. G., Beard, J. W., and Rous, P., *J. Exp. Med.*, 1936, 64, 79
- 7 Kidd, J. G., and Rous, P., *J. Exp. Med.*, 1940, 71, 813
- 8 Rous, P., and Kidd, J. G., *J. Exp. Med.*, 1941, 73, 365
- 9 Hurst, E. W., in Shope, R. E., *J. Exp. Med.*, 1933, 58, 607. Rous, P., and Beard, J. W., *J. Exp. Med.*, 1934, 60, 701. Ladewig, P., *Virchows Arch. path. Anat.*, 1936-37, 298, 636
- 10 Drinker, C. K., and Churchill, E. D., *Proc. Roy. Soc. London, Series B*, 1927, 101, 462
- 11 Fischer, B., *Mitteil. med. Week.*, 1906, 53, 2041
- 12 Topley, W. W. C., and Wilson, G. S., *The principles of bacteriology and immunity*, London, Edward Arnold & Co., 2nd edition, 1936, 227
- 13 Rivers, T. M., Some general aspects of filterable viruses, in Rivers, T. M., *Filterable viruses*, Baltimore, The Williams & Wilkins Co., 1928, 14

14. Olitsky, P. K., and Schlesinger, R. W., *Science*, 1941, 83, 574
15. Sprunt, D. H., *J. Exp. Med.*, 1941, 74, 81
16. Rous, P., Kidd, J. G., and Beard, J. W., *J. Exp. Med.*, 1936, 64, 385
17. Bryan, W. R., and Beard, J. W., *J. Infect. Dis.*, 1939, 65, 306
18. Bryan, W. R., and Beard, J. W., *J. Infect. Dis.*, 1940, 66, 245



## EXPLANATION OF PLATES

All of the specimens were stained with eosin and methylene blue

The photographs were made by Mr Joseph B Haulenbeek

## PLATE 2

FIG 1 Normal skin, from the abdomen of a normal domestic rabbit It has been overstained with hematoxylin to make the thin epidermal layer more evident  $\times 18$

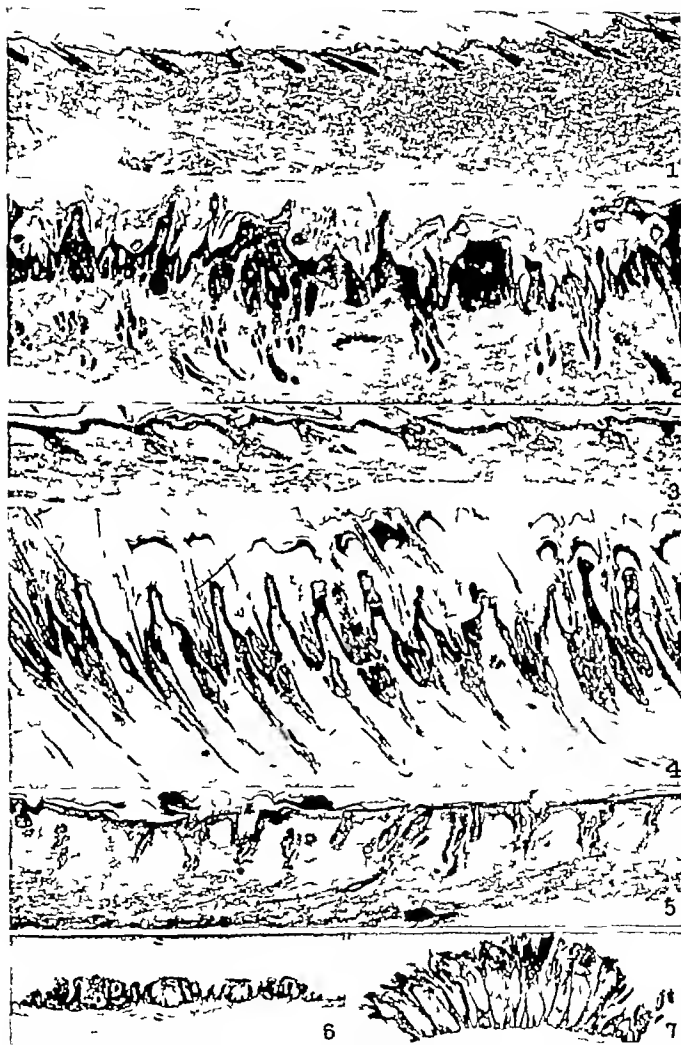
FIG 2 Portion of an area of abdominal skin which had been tarred twice a week for 2 weeks Biopsy 2 days after last application  $\times 18$

FIG 3 Skin treated with turpentine and acetone The mixture had been applied five times at 2 day intervals Biopsy 24 hours after last treatment  $\times 18$

FIG 4 To show the skin alterations induced by four applications at 2 day intervals of a saturated solution of Scharlach R in benzene containing 0.3 per cent methylcholanthrene  $\times 18$

FIG 5 Illustrating the marked hyperplasia of normal skin after scarification Specimen taken 8 days after scarification  $\times 18$

FIGS 6 and 7 Cross section of the papillomatous masses formed after broadcast tattoo inoculation of normal skin (Fig 6) and of methylcholanthrene treated skin (Fig 7) of the same rabbit The growths were removed and sectioned 42 days after virus inoculation Only a portion of the mass on the methylcholanthrene treated skin is shown  $\times 2\frac{1}{2}$



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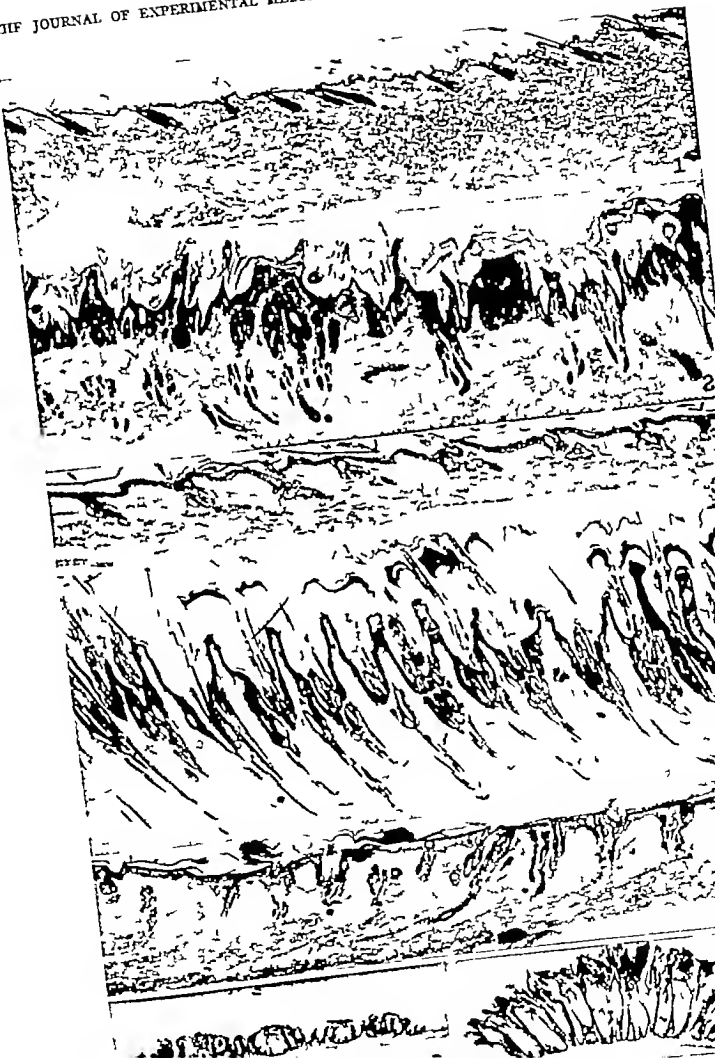
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### PLATE 3

FIGS. 8 to 12 To illustrate the changes induced by scarification of methylcholanthrene treated skin. All the specimens were taken from the same rabbit.

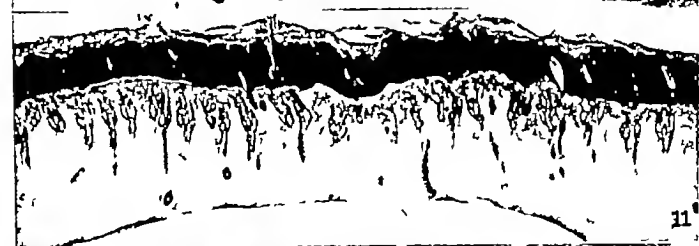
FIG. 8 Methylcholanthrene treated skin before scarification. 0.3 per cent methylcholanthrene in benzene had been applied to it four times at 2 day intervals. Biopsy 24 hours after last treatment.  $\times 18$ .

FIG. 9 5 hours after scarification. The surface epithelium has been almost completely removed together with some connective tissue and the upper portion of the hair follicle shafts. A scab is forming on the surface.  $\times 18$ .

FIG. 10 24 hours after scarification. The scab is unusually thick as result of superficial necrosis involving both the connective tissue and hair follicle shafts. From the latter epithelial regeneration is already taking place, the new cells extending between scab and connective tissue. The bracketed region is shown at greater magnification in FIG. 12.  $\times 18$ .

FIG. 11 48 hours after scarification. Epithelial regeneration is now complete and the denuded surface is covered with markedly hyperplastic epidermis. The sebaceous glands are also hyperplastic and many are distended with secretion. Hence their prominence as compared with those of FIG. 8.  $\times 18$ .

FIG. 12 The bracketed region of FIG. 10 at higher magnification. The epithelium is spreading laterally from the shafts of the hair follicles to form umbrella like structures. Some of the new epidermal cells can be seen extending irregularly into crevices in the fibrous corium.  $\times 60$ .





## RED CELL AND PLASMA VOLUMES (CIRCULATING AND TOTAL) AS DETERMINED BY RADIO IRON\* AND BY DYE†

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The total blood volume is usually calculated from the plasma volume and the venous hematocrit with the use of the formula

$$\text{Total blood volume} = \frac{\text{Plasma volume}}{(1 - \text{venous hematocrit})}$$

The plasma volume has commonly been determined by one of the several dye dilution methods and as performed has been assumed to be accurate to within 5 per cent. The venous hematocrit has been assumed to be representative of the average hematocrit of all the blood in the vascular system. Application of the principles of hydrodynamics to the problems of blood flow and blood volume indicates that neither of these assumptions is valid. The experimental data to be presented confirm the fact that the blood volume values calculated from the plasma volume and venous hematocrit are subject to considerable systematic error.

In the observations subsequently to be described, we shall demonstrate by several techniques that the mass of red blood cells in the body is approximately 75 per cent of the commonly accepted amount, that few of these cells are immobilized in "reservoirs," that the mixing time for erythrocytes is much more rapid than that for dyes, and that the usually accepted times for mixing of dyes in the vascular system probably represent mixing in the "axial stream" only, and not in the entire contents of the vessels.

About 100 years ago Peclet (11, 15) pointed out that when a liquid moves over a solid surface a sluggishly moving fluid film exists on the surface of a stationary fluid film. The character of both films is entirely different from that of the main body of moving fluid and they form a zone between the rapidly moving fluid and the wall,

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† We are indebted to Eli Lilly and Company for aid in conducting this work.



acting toward the transportation of heat, vapor, and matter as though they were a separate material. The presence of these films has been verified by many investigators (10), and their properties are controlling factors in many processes. Their characteristics receive important engineering consideration, and they deserve equally as much attention from the physiologist.

An instance of the importance of these films is encountered in a consideration of the mechanics of mixing of particulate matter in a vessel. A plot of the velocity of a fluid against its distance from the wall of the containing vessel shows that there is no motion of the fluid at the boundary wall (13), and that with progression toward the center of the tube the velocity of the motion increases. Near the wall of the vessel the fluid flow is in a path parallel to the wall, and there is no component of velocity at right angles to the latter. Approaching the center of the vessel, however, the fluid elements begin to travel in forward moving spirals although the "net flow" is still parallel to the wall. The path of any given particle now has a large component of velocity at right angles to the vessel wall. Thus, from a condition of "viscous," or "straight line" flow near the wall we have progressed to "turbulent" flow in the center. These two types of flow exert a profound and very different effect upon the mixing of the neighboring fluid layers.

Applying these principles to the problem of hemodynamics it is evident that when blood flows through a blood vessel, two films of plasma exist along the wall of the vessel, one without motion, and the other with a sluggish motion parallel to the wall of the blood vessel. The flow of this film is "viscous" or "straight line," and there is no turbulence or mixing between these films and the rest of the contents of the vessel. Microscopic inspection of small blood vessels shows that these films are for the most part devoid of erythrocytes.

The thickness of the surface films varies inversely with the velocity of flow of the main body of the fluid contents, and the percentage that they constitute of the total fluid contents of a vessel varies inversely with the diameter. In the blood vascular system as the arteries and arterioles become smaller and approach the capillary bed there is no increased velocity of blood flow, but an actual *decrease* in velocity. There is also a great increase in the number of vessels and a decrease in their diameter. Therefore the surface films might be expected to constitute a progressively increasing proportion of the total contents of small arteries, arterioles, and capillaries. That this should be the case is demonstrated by the following formula.

The total volume of the fluid in a unit length of vessel is  $\pi r_1^2$  where  $r_1$  is the radius of the vessel. If  $t$  is the thickness of the *combined stationary and sluggish films*, which consist of plasma only, then the radius of the body of fluid in axial flow is  $r_1 - t = r_2$ , and the volume of fluid in the axial stream is  $\pi r_2^2$ . The volume of plasma in the films is then  $\pi r_1^2 - \pi r_2^2$ . The fraction ( $f$ ) of total plasma in the films is then

$$\frac{\pi r_1^2 - \pi r_2^2}{\pi r_1^2}, \text{ eliminating } \pi$$

$$(1) \text{ This may be expressed as } \frac{r_1^2 - r_2^2}{r_1^2} = f$$

$$(2) \text{ Equation (1) may be expanded to } \frac{(r_1 - r_2)(r_1 + r_2)}{r_1^2} = f$$

(3) Now since  $r_1 - r_2 = l$  which is constant for a constant velocity of fluid flow we can substitute (3) in (2)  $\frac{(r_1 + r_2)k}{r_1^2} = f$  and, since  $r_1$  approximates  $r_2$  where  $l$  is small, we have  $\frac{2r_1 k}{r_1^2} = f$  or  $\frac{r_1 \times k_1}{r_1^2} = f$  eliminating one  $r_1$   $\frac{k_1}{r_1} = f$  Thus, since  $f$

is shown to be indirectly proportional to the radius, as the vessel becomes smaller the fraction of plasma in sluggish movement increases. It is obvious that this relationship does not hold in capillaries where the diameter approaches that of a single red cell. However, Zweifach and Kossmann (18) found that the individual capillaries vary considerably in size, the fluctuations noticed being from 3 to 10 micra in diameter.

It has been observed by many investigators that rapid plasma flow may occur in vessels apparently too small to permit passage of red cells.

The influence of these surface films on determinations of blood volume was first pointed out by Hooper, Smith, Belt, and Whipple (9), who recognized that the hematocrit of capillary blood was considerably lower than that of venous blood due to the existence in small vessels of a central 'axial stream' of cell rich blood and a peripheral, relatively cell free still space. Using the carbon monoxide inhalation and Welcker viviperfusion methods to determine the volume of erythrocytes ('direct methods') they demonstrated that the total mass of erythrocytes was 20 to 30 per cent less than the values obtained by calculations based on the plasma volume and venous hematocrit.

Fahraeus (2) emphasized the fact that the blood flowing through a capillary has a much lower ratio between cells and plasma than the blood which flows from its cut end—an observation which is explained by the relatively great velocity of flow of the cell rich axial stream and the slow flow of the peripheral films.

Using erythrocytes 'tagged' with radioactive iron, and determining their dilution in the circulating blood Hahn, Balfour, Ross, Bale, and Whipple (6) confirmed the fact that the total mass of red blood cells in the body is approximately 25 per cent less than that indicated by the plasma volume-venous hematocrit calculations.

Stead and Ebert (14) recently arrived at the same conclusion by demonstrating the discrepancy between hematocrit and hemoglobin changes produced by bleeding and the amounts of blood removed.

The surface film-axial stream relationship existing in the blood vessels and the differences in type of particle motion within them not only influence the distribution of erythrocytes in these vessels but also operate to retard the passage of dyes from the rapidly moving turbulent axial stream into the sluggishly moving and stationary peripheral films. This difference in type of mixing has been neglected in the usual plasma volume determination and has introduced considerable error into the procedure, an error which in turn has been reflected in the blood volume estimation.

### Methods

Unexercised, healthy normal or anemic dogs were used for all experiments. To avoid lipemia the food was withheld for 18 hours before plasma volume determinations were made. Plasma volumes were determined by a modification of the brilliant vital red procedure (9). The amount of dye injected was sufficient to produce such a

concentration in the plasma sample that the colorimeter reading was within 10 per cent of the standard diluted dye reading. A single sample of plasma was secured 4 minutes after administration of the dye, care being exercised to avoid stasis in the vein and hemolysis. The anticoagulant used was 1.4 per cent sodium oxalate solution.

The mass of red blood cells was determined by four techniques: (a) by viviperfusion and determination of the total amount of hemoglobin removed (9), (b) by determination of the amount of tagged blood cells which had to be withdrawn to remove completely from the circulation all of the radioactive iron tagged cells (which had previously been built up in the circulation by methods described (7) elsewhere), (c) by determining the dilution of radioactive tagged cells after removal of a known quantity of blood (and radioactive tagged cells) when regeneration of blood had restored the original hematocrit, (d) by determining the dilution in the circulation of injected radioactive tagged erythrocytes (6).

The technique of the modified Welcker viviperfusion method has been described elsewhere (16). The perfusate was collected in isotonic sodium oxalate solution, and the hematocrit of an aliquot determined. Total iron content or radioactive iron concentration and hemoglobin content were determined on packed red cells, (since the use of whole blood for the latter procedure may lead to erroneous results (17)). Hemoglobin determinations were performed according to the method of Newcomer (12).

Determination of the red cell volume by either of the depletion techniques (method 2 or 3) was accomplished as follows. An iron depleted anemic dog was fed a single dose of radioactive iron and regeneration of hemoglobin was allowed to proceed until the concentration of this material in the blood was nearly constant. The animal was then bled repeatedly over a period of several weeks until all of the radioactive tagged cells were removed from the circulation. The radioactivity of the blood removed at each bleeding was determined, and the total activity of all the removed blood calculated. The total red blood cell volume was then calculated by dividing the total activity removed by the initial concentration of radioactivity per unit volume of cells.

A modification of this procedure consisted in bleeding the animal several times and allowing blood regeneration to restore the hematocrit to the same level that existed prior to the hemorrhages. Assuming the red blood cell volume to be the same at the same hematocrit level, this volume was then calculated by dividing the total radioactivity removed in the bleedings by the difference in concentration of the isotope in the circulating blood before bleeding and after regeneration.

The donor cell dilution method of determining red blood cell volume has been described briefly elsewhere (6). It has distinct advantages over other methods of cell volume determinations. It can be performed on normal animals or animals with any degree of anemia. The conditions under which it may be carried out are physiological and do not disturb the normal hemodynamics or vascular system. The tagged cells are not subject to loss from the vascular system (as are dyes and carbon monoxide). Erythrocytes "tagged" or "labelled" with radioactive iron were drawn from a donor dog in whom hemoglobin regeneration with radioactive iron had been produced (7). These cells, containing a known amount of radioactive iron, were then administered intravenously (in a period of 30 seconds) to the dog under study (whose own cells

contained none or a known concentration of radioactive material) The degree of dilution of the radioactive tagged cells was determined on blood samples removed at 2, 4, 6, 10, and 15 minutes and at daily intervals following the injection Coagulation of these samples was prevented with isotonic sodium oxalate, they were centrifuged 35 minutes at 2500 R.P.M., the cell-plasma ratio was determined, and the cells were subjected to wet ashing and radioactivity determination as described elsewhere (4, 5) The red blood cell volume was then calculated by dividing the total radioactivity in the injected donor erythrocytes by the radioactivity per unit volume of cells in the sample.

TABLE I  
*Red Cell Volume and Average Body Hematocrit by Viviperfusion Method*

Dog	Weight	Plasma volume by dye	Cell volume calculated by dye	Cell volume determined	Blood volume determined	Jugular hematocrit	Average hematocrit	Ratio cell volume determined to cell volume by dye	Ratio average hematocrit to jugular hematocrit
	kg	ml.	ml.	ml	ml.	per cent	per cent	per cent	per cent
33-329	15.6	700	660	400	1100	49.0	36	61	74
40-167	14.5	680	725	495	1175	51.3	42	68	82
39-161	8.3	320	310	285	605	48.6	47	92	97
38-320	14.9	760	240	160	920	23.5	17	67	72
37-186	6.4	285	155	130	415	37.4	32	84	85
Pup 3-A		235	145	115	350	37.5	32	79	85
" 4-A		285	170	115	400	36.9	29	68	79
" 5-A	6.2	295	180	125	420	38.0	30	70	79
" 6-A	6.4	375	190	115	490	33.4	24	61	72
" 1 B*	2.1	165	67	30	195	28.6	15	45	52
" 1-C	10.3	395	280	210	605	41.2	35	75	85
" 2-C	4.7	285	145	120	405	32.6	30	83	92
" 5-E	16.0	720	725	570	1290	50.0	44	72	88
Average								71	80

\* 1 B emaciated.

The radioactive isotope of iron,  $Fe^{59}$  used for these experiments was prepared by deuteron bombardment of iron and had a half period of 47 days. Preparation of samples for radioactivity determination has been described (4, 5)

#### EXPERIMENTAL OBSERVATIONS

##### 1 The Erythrocyte Volume As Indicated by Viviperfusion

When properly performed viviperfusion very effectively removes practically all red cells from the body The hematocrit of the perfusate is usually below 1 per cent terminally, and the tissues (with the exceptions of the spleen and bone marrow) are bloodless at autopsy and microscopically As shown by the iron analyses of Hahn and Whipple (8), the total mass of erythrocytes left in the body after viviperfusion does not amount to more than 1 to 2 per

cent of the total cell mass. Thus the values for erythrocyte volumes shown in Table I are subject to an error of not more than 5 per cent. Comparison of the values for red blood cell volume as determined by viviperfusion is made with the values calculated from the plasma volume-jugular hematocrit. It is evident that in every instance the latter method gives results 15 to 30 per cent higher than those obtained by viviperfusion.

### 2 The Erythrocyte Volume As Determined by Depletion of Radioactive Iron Containing Cells

In Table II the volume of erythrocytes as calculated from the plasma volume and jugular hematocrit is compared with the volume as determined by depletion of radioactive iron containing cells over a period of weeks by repeated

TABLE II  
*Comparison of Total Red Blood Cell Volumes As Calculated from Plasma Volumes and Determined Directly by Radio Iron Hemoglobin*

Dog	Red cell volume determined directly	Red cell volume calculated from plasma volume	Plasma volume by dye	Jugular hematocrit	Average body hematocrit	Ratio red cell volumes
	ml	ml	ml	per cent	per cent	per cent
By depletion of radio iron in circulation by repeated hemorrhage						
39 196	350	460	575	43.2	37.8	0.76
38-170	300	490	475	50.5	38.8	0.61
By change in concentration of radio iron in circulation						
38-137	270	405	590	40.7	31.4	0.67
39 133	215	310	455	39.7	32.0	0.69
37-202	160	280	570	31.6	22.0	0.57
37 202	120	200	810	18.6	12.9	0.60

hemorrhages. Since the animals used in this type of experiment were iron deficient and only a single feeding of a small amount of iron was given, all of the radioactive isotope was present in circulating erythrocytes at the beginning of the experiments. Complete removal of these tagged cells reasonably can be assumed to indicate complete removal of all the cells present in the vascular system at the beginning of the experiment. The mass of cells as determined by this procedure is found to be 24 and 39 per cent lower than the values calculated from the plasma volume and jugular hematocrit.

### 3 The Erythrocyte Volume As Indicated by the Regeneration Dilution of Radioactive Iron Containing Cells

The volume of erythrocytes determined by regeneration dilution of radioactive iron containing cells following removal by bleeding of a known quantity of blood is compared with the values calculated from plasma volume and jugular

hematocrit in Table II. The latter method gives values considerably higher than those obtained with the dilution method.

#### 4 Erythrocyte Volume Determined by Injection of Tagged Cells

Table III shows the erythrocyte volume as indicated by determinations of dilution of injected radioactive iron containing cells. The rapidity with which these cells are mixed with those of the entire vascular system is evidenced by the almost identical values obtained after 2 minute and 24 hour mixing periods. It is improbable that such rapid and complete mixing would

TABLE III

*Circulating and Total Red Cell Mass Determined by the Radioactive Donor Cell Method*

Dog	Activity injected cells	Activity in recipient cells						Average activity concentra- tion 4, 6, and 10 min.	Circu- lating red cell volume	Total RBC volume
		Counts/min per 100 ml RBC								
		2 min.	4 min.	6 min.	10 min.	24 hrs.	Other			
	counts / min							counts/ min./RBC %	ml	ml
39-307	905	233	196	209	206	222	208 (8 days)	204	445	405
40-149	705	231	183	187			208 (5 days)	185	380	340
36-196	1260	438	427	430	440		453 (3 days)	432	292	278
39-144	128	58	48	51	42	54	48 (4 days)	47	272	237
39-88	761	162	168	157	168	148	148 (3 days)	164	465	513
39-194	1135	310	286	289	302			292	389	
39-193	491	98	87	88	78			84		
39-299	558		334	386		311		360	155	180
40-183	865				187	198			460	440
39-196	1680				398	410			420	410
4-E	1680				537	480			315	350
Average									355	350

\* Scale of four Geiger counter

occur if any considerable proportion of the total volume of erythrocytes were immobilized in splenic sinusoids or elsewhere in the body.

#### DISCUSSION

Our results indicate that the total erythrocyte volume as determined by direct procedures is 10 to 40 per cent less than the volumes derived by the plasma jugular hematocrit method. The total blood volume can be ascertained by adding the cell volume (determined by radioactive tagged erythrocyte method) and the plasma volume (determined by dye dilution method). The average hematocrit value for the entire contents of the vascular system can then be determined by dividing the directly determined cell volume by the

total blood volume. This average hematocrit is invariably, considerably (about 20 per cent) lower than that of the large vessels. To compensate for the relatively greater number of cells present in the large vessels, the cell-plasma ratio in the small vessels must, therefore, be even less than that of the average. The theoretical explanation for this finding has been presented above in the discussion of the peripheral plasma films.

No significant fraction of the erythrocyte volume can be immobilized in the spleen, liver, or other regions, since the volume of cells in rapid circulation (as indicated by the values for erythrocyte volume determined after only 2 or 4 minutes mixing of injected, radioactive tagged cells) is practically identical with the total volume of erythrocytes (indicated by the volume found after 24 hour, or longer, periods of mixing). It is improbable that such complete mixing could occur so rapidly if many cells were immobilized, and it appears that practically all red blood cells in the dog are in active circulation. Similar conclusions have recently been drawn by Ebert and Stead (1).

Since there is no evidence that any considerable fraction of the erythrocyte volume is immobilized, it may be concluded that all the red blood cells of the dog are in active circulation and that the *circulating erythrocyte volume* is practically identical with the *total erythrocyte volume*. Since the cell-plasma ratio of the rapidly flowing axial streams in various vessels is fairly constant, the jugular hematocrit may be assumed to be representative of this ratio for the rapidly circulating ("axial stream") blood, and the actual *rapidly circulating blood volume* may be calculated by dividing the cell volume (as determined with the donor cell method) by the jugular hematocrit. The rapidly circulating blood volume as determined in this manner is considerably lower than the total blood volume ascertained by the addition of the cell volume (directly determined by the isotope dilution method) and the plasma volume (from the dye procedure). Tables IV and V summarize these differences.

The amount of plasma in rapid circulation ("rapidly circulating plasma volume") can be calculated from these values by subtracting the determined cell volume from the calculated rapidly circulating blood volume. In similar fashion, if the value for plasma volume as determined by the dye method is accepted as representative of the *total* plasma volume, the difference between this value and "the rapidly circulating plasma volume" is a measure of the fraction of the plasma in relatively sluggish circulation. This fraction amounts to 6 to 37 per cent in the series of animals listed in Tables IV and V.

The previously described laws of hydrodynamics apply to the passage of dyes between the various fluid layers of the circulating blood as well as to the mixing of erythrocytes. The passage of dyes from the central turbulent stream into the peripheral films occurs only by the slow process of diffusion. Since we have demonstrated that these peripheral films may constitute a very considerable proportion (21 per cent) of the total amount of plasma, appreciable

TABLE IV

*The Partition of Plasma in the Vascular System by Radio Iron*

Dog	Weight	Jugular hematocrit	rac volume	Blood volume circulating	Plasma volume circulating	Plasma volume by dye	Plasma volume difference	Total plasma volume in slow circulation
	kg	per cent	ml.	ml	ml.	ml		per cent
39-307		51.4	445	865	420	480	60	13
39-144	9.5	44.0	255	580	325	485	160	33
39-88		53.7	465	865	400	520	120	23
39-194	17.0	40.0	389	970	580	720	140	19
40-149	10.0	42.4	380	900	520	525	5	1
39-299	14.3	21.3	155	730	575	645	70	11
40-183	13.5	48.0	460	960	500	585	85	15
39-196	15.1	38.2	420	1100	680	645	-35	
4-E	16.0	39.4	315	800	485	725	240	33
33-329	15.6	49.0	400	815	415	700	285	41
3-A		37.5	115	305	190	235	45	19
4-A		36.9	115	310	195	285	90	32
5-A	6.2	38.0	125	330	205	295	90	31
37-186	6.4	37.4	130	350	220	285	65	23
38-320	14.9	23.5	160	680	520	760	240	32
40-167	14.5	51.3	495	1160	665	680	15	2
39-161	8.3	48.6	285	535	300	320	20	6
36-196		39.0	290	745	455	565	110	19

TABLE V

*Partition of Plasma in the Vascular System at Various Hematocrit Levels*

Dog	Weight	Hematocrit	rac volume determined	Blood volume circulating	Plasma volume circulating	Plasma volume by dye	Plasma volume difference	Total plasma volume in slow circulation
	kg	per cent	ml.	ml.	ml	ml	ml.	per cent
40-183	13.5	53.2	525	985	460	580	120	20
		48.0	460	960	500	585	85	15
		29.9	212	710	498	745	247	33
		27.8	202	725	513	700	175	25
39-196	15.1	38.2	420	1100	680	645	-35	
		36.5	345	945	600	640	40	6
		27.0	215	795	580	820	240	29
		26.9	235	875	640	820	180	22
		23.8	200	840	640	700	60	9
4-E	16.0	39.4	315	800	485	725	240	33
		27.6	230	830	600	955	355	37
		27.4	270	985	715	955	240	25
		22.6	205	905	700	815	115	14
39-320	10.0	49.2	260	530	270	370	100	27
		25.2	155	615	460	490	30	6
38-137	10.7	48.7	410	840	430	480	50	10



difference in time of mixing in the axial stream and total fluid may be predicted. Also, since dyes are presumably lost from the circulation by various processes, if the time interval between samples is great enough to allow for complete diffusion, results obtained by these methods are likely to be falsely high. Theoretically, there should be a complex type of time curve for the concentration of dye in the blood, since at least three processes are taking place simultaneously:

1. Turbulent mixing of the dye in the large vessels and in the axial stream of small vessels

2. Diffusion of the dye into the peripheral sluggishly moving and stationary plasma films

3. Loss of dye through removal by the reticulo-endothelial system and excretion through the biliary tract

Conceivably each of these processes might be demonstrated graphically if concentration of dye is plotted against time, providing that all or any two did not have rates of such a character that the curves approached similarity despite varying order of functions. Actually such differences in the curves of plasma volume determinations can be demonstrated. Inspection of the curves of various investigators using the Evans blue (T-1824) as well as the brilliant vital red dye, indicates at least two phases of distribution of dye in the vascular system, and personal observations indicate that a third may well be present. Gibson and Evans (3) divide their curve into two components which they term the "mixing phase" and the "disappearance phase". The intersection of the tangents of these curves is assumed to represent the true mixing time of the dye in all the plasma, and the point of intersection of the extrapolated tangent with the ordinate is claimed to indicate the value for the optical density (a function of the true plasma volume) at the time of dye injection. More careful study of the character of these curves indicates that three distinct phases may be demonstrated. Not only the slopes, but also the shapes of these curves differ, the first two (comprising the mixing curve) being exponential, while the disappearance curve is almost linear.

The two phases of the mixing curve are produced by the mixing in the axial stream, and the diffusion mixing of the peripheral plasma films. Careful analysis indicates that the latter process may frequently extend over a time much longer than that commonly assumed to allow complete mixing. Calculations based on dye dilutions at periods before complete mixing has occurred yield plasma volumes which are low. In spite of this fact, however, the plasma volumes so determined are still considerably higher than the rapidly circulating plasma volumes.

The rapidly circulating and sluggishly flowing plasma fractions are not to be considered as separate entities, inasmuch as there is constant (although slow) interchange between them. They do, however, greatly influence consideration of blood flow and blood volume.

## SUMMARY

1 Application of the principles of hydrodynamics to the problem of blood flow and blood volume indicates that the calculation of blood volume and cell volume from the venous hematocrit and plasma volume (as determined by the dye method) is subject to considerable error

2 This conclusion is borne out by determinations of total cell volume by viviperfusion and with the use of radioactive iron tagged erythrocytes, which have shown the erythrocyte volume to be only 70 to 75 per cent of the volume indicated by the previously mentioned calculations

3 The average hematocrit of the entire vascular system is considerably lower than the hematocrit of the large vessels, and the cell plasma ratio of the smaller vessels is still less.

4 In the dog there are no considerable stores of immobilized erythrocytes, and the total erythrocyte volume and circulating erythrocyte volume are identical

5 The "rapidly circulating blood volume" can be determined by dividing the erythrocyte volume by the venous hematocrit, and is found to be considerably less than the total blood volume.

6 The concept of the "rapidly circulating plasma volume" is introduced, and it is found to be approximately 80 per cent of the total plasma volume

7 The volume of plasma in the peripheral, cell free, sluggishly moving plasma films plus that contained in small vessels in which no red cells are present, is also determined and found to be approximately 20 per cent of the entire plasma volume

8 The existence and magnitude of these fractions of the blood plasma volume should receive consideration in studies of blood flow and blood volume.

## BIBLIOGRAPHY

- 1 Ebert R V and Stead, E A. *Am. J Med Sc*, 1941, 201, 655
- 2 Fahreus, R., *Physiol Rev*, 1929 9, 241
- 3 Gibson J G 2nd, and Evans, W A Jr, *J Clin Inv*, 1937, 16, 301
- 4 Hahn P F Bale, W F, and Balfour W M, *Am J Physiol* in press.
- 5 Hahn, P F, Bale W F, Lawrence, E O, and Whipple, G H., *J Exp Med*, 1939 69, 739
- 6 Hahn, P F, Balfour W M Ross, J F, Bale, W F and Whipple, G H *Science* 1941, 93, 87
- 7 Hahn P F, Ross J F Bale W F, and Whipple, G H. *J Exp Med* 1940, 71, 731
- 8 Hahn P F and Whipple G H, *Am J Med Sc*, 1936, 191, 24
- 9 Hooper, C. W, Smith, H. P, Belt, A. E and Whipple, G H. *Am J Physiol*, 1920, 51, 205
- 10 Langmuir I. *Phys Rev* 1912, 34, 421
- 11 Peclet Jean Claude Eugène *Traité de la chaleur*, 1844, chapter VIII, 131
- 12 Robschey, F S, *J Biol Chem.* 1920, 41, 209

- 13 Stanton, T E , Marshall, D , and Brvant, C. N , *Proc Roy Soc London, Series A*, 1920, 97, 413
- 14 Stead E A , and Ebert, R. V , *Am J Physiol* , 1941, 132, 411
- 15 Walker W H , Lewis, W K , and MacAdams, W H , Principles of chemical engineering New York, McGraw Hill Book Company, 1927
- 16 Whipple, G H , *Am J Physiol* , 1926, 76, 693
- 17 Wu, H , *J Biochem* , 1922, 2, 173
- 18 Zweifach, B W , and Kossmann, C E , *Am J Physiol*, 1937, 120, 24

# INFLUENCE OF AGE ON SUSCEPTIBILITY OF MICE TO ST LOUIS ENCEPHALITIS VIRUS AND ON THE DISTRIBUTION OF LESIONS\*

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## PLATE 4

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Evidence has accumulated that young mice are more susceptible than older ones to many neurotropic viruses if they are inoculated by a peripheral route. The most significant decline in susceptibility apparently occurs as mice pass 2 weeks of age, but there is uncertainty concerning the factors which contribute to this age difference. Andervont (1) showed that 2 week-old mice were less resistant than adults to intracutaneous inoculation of herpetic virus into the abdominal skin and Theller (2) demonstrated the greater susceptibility of young mice to the intraperitoneal inoculation of the virus of yellow fever.

Several explanations have been advanced to account for the greater susceptibility of young mice to peripherally inoculated virus. Sabin and Olitsky (3, 4) suggested that the myoneural junction or specialized nerve endings might impede the progress of the virus in adult mice inoculated intramuscularly with the virus of vesicular stomatitis. To explain the difference in susceptibility when the same virus was introduced by the olfactory route they offered the explanation that a central barrier preventing the passage of the virus existed in adult mice between the primary olfactory centers of the telencephalon and the remainder of the brain. King (5), studying Eastern equine encephalomyelitis, believed it probable that the increased resistance of older mice to peripheral inoculation could be explained by a change in the brain tissue itself such as might be brought about by increased cell maturity,—myelination, change in water content, and in reaction to specific and non-specific injury. Following intramuscular inoculation of the virus of Western equine encephalomyelitis Sabin and Olitsky (6, 7) observed in mice 2 weeks of age, a high incidence of symptoms of encephalitis with lesions indicative of invasion along the olfactory or other pathways without evidence of either diffuse hemato-encephalitic spread or progression by way of the local nerves. On the other hand a high incidence of symptoms attributable to ascending infection was observed in mice 3 weeks of age. At one month of age and beyond, many mice were entirely resistant following intramuscular inoculation.

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They attributed the difference between the first two groups to the greater permeability of certain blood vessels of the young animal for the virus, and the difference between the latter two groups to changes in the muscle or specialized nerve endings.

A difference in invasive capacity between fresh and fixed viruses, emphasized by the studies of King (5) and Casals (8), may also play a rôle in determining the greater susceptibility of young animals. Other factors of possible significance in this respect are the ability of a virus to multiply in the blood (Hurst (9), equine encephalomyelitis, monkey, and guinea pig) or other tissues of the body, and the rate at which antibodies are produced (Morgan (10), Eastern equine encephalomyelitis, mice) at different ages.

The influence of age on the susceptibility of mice inoculated intraperitoneally with the virus of St. Louis encephalitis has been determined in the present investigation. The explanation for the difference in susceptibility between young and old animals has been sought in a study of the distribution of lesions in mice between 2 and 8 weeks of age killed at intervals following intraperitoneal inoculation. The distribution of the lesions has been compared with that which followed intranasal inoculation in adult mice. Special attention has been directed to two possibilities: (1) that evidence of a direct hematogenous invasion of the C N S might be found in young mice, (2) that young mice inoculated intraperitoneally, in contrast to older mice, might show a distribution of lesions coinciding with that found when the olfactory route of inoculation was used.

### *Material and Methods*

The Hubbard Strain of St. Louis encephalitis virus, isolated in 1937, was used in this study. At present the virus has a constant infective titer as great as  $10^{-7}$  when measured by intracerebral inoculation of mice 2 months of age. On some occasions the infective titer so measured reaches  $10^{-8}$ . When these experiments were begun, the virus had been carried through approximately 100 successive passages in the mouse brain. The material for injection was prepared in a uniform manner for all experiments. Brains removed from mice in the convulsive stages of encephalitis were kept in the freezing unit of the refrigerator ( $-15^{\circ}$  to  $-20^{\circ}\text{C}$ ) for 1 to 2 days. Brains, shown to be bacteriologically sterile, were ground without abrasive and suspended in sufficient nutrient broth (pH 7.4) to make a 10 per cent suspension. Following centrifugation at 200 R P M for 2 minutes the supernatant fluid was drawn off and used to make further tenfold dilutions in nutrient broth. For a given route of inoculation the same quantity of fluid inoculum was used irrespective of the size of the mouse.

For the susceptibility studies, groups of mice of different ages were usually inoculated in the same experiment. When this was not possible because of the difficulty of having on hand a sufficient number of mice of all the required ages, the titer of the virus was confirmed by the intracerebral inoculation of mice approximately 2 months of age. Swiss mice obtained from a single source were used with the following exception. Part of the mice in the 2 weeks age group were white mice of the "Old Buffalo" strain. However, the latter strain and the Swiss mice which we have used

have shown the same degree of susceptibility to the virus of St. Louis encephalitis when inoculated intracerebrally.

For the anatomical studies the virus was instilled intranasally and inoculated intraperitoneally. Usually the mice of a single experiment were killed at spaced intervals preceding the time at which it might be expected that clinical signs of the disease would develop. Several mice of each group were kept until symptoms had appeared. The brains were fixed in a mixture of aqueous corrosive sublimate and absolute alcohol, embedded in paraffin, and sectioned serially in a frontal plane at  $20\ \mu$ . Every third slide of each series was stained with cresyl violet, the maximum distance separating stained slides being 0.4 mm. With few exceptions representative levels of the spinal cords were cut in all mice of the series inoculated intraperitoneally. Other cords were preserved and cut when it appeared desirable.

164 brains were obtained, 25 from mice 6 to 8 weeks of age instilled intranasally with  $10^{-3}$  or  $10^{-4}$  dilution of virus and 139 from mice 2 to 8 weeks of age inoculated intraperitoneally with  $10^{-1}$  and higher dilutions of virus.

### *Susceptibility to Intracerebral, Intranasal, and Intraperitoneal Inoculation of Virus*

*Intracerebral Inoculation*:—In each of two experiments groups of 4 mice, 3 weeks, 6 weeks, and 15 months of age were inoculated intracerebrally with 0.03 cc. of tenfold dilutions of virus in broth. In a 3rd experiment 2 groups of mice 8 weeks and 10 months of age were inoculated with corresponding dilutions of virus. Finally two groups of mice, 2 weeks and 3 months of age, were inoculated in a similar manner. As shown in Table I, mice of all ages were uniformly infected when they received  $10^{-7}$  dilution of virus intracerebrally. When the titer of the virus reached  $10^{-8}$  approximately the same number of the mice died in all groups.

*Intranasal Inoculation*:—Groups of 8 mice, 3 weeks, 6 weeks, and 15 weeks of age were inoculated intranasally with 0.03 cc. of dilutions of virus in broth. Again no difference in the response of the various age groups could be distinguished (Table II). At all ages at least a part of the mice died following intranasal instillation of the  $10^{-4}$  dilution of the virus while only an occasional mouse in any age group showed evidence of infection following instillation of the  $10^{-8}$  dilution. The same results were obtained in other experiments using these three age groups, and also in one experiment in which a group of mice 10 months of age was used.

*Intraperitoneal Inoculation*:—In contrast to the intracerebral and intranasal routes, the age of the mice influenced the results when the virus was inoculated intraperitoneally, (Table III). Tenfold dilutions of the virus in broth were injected in 0.25 cc. amounts by this route. When groups of mice 3, 6, and 15 weeks of age were used, most of the mice in the oldest age group remained well following the inoculation of a  $10^{-1}$  dilution of the virus. Of mice 6 weeks of age, a slightly greater number succumbed to this amount of virus but only an

occasional mouse died following the inoculation of the  $10^{-2}$  dilution. On the other hand all mice 3 weeks of age succumbed when inoculated intraperitoneally

TABLE I

*Susceptibility of Mice of Different Ages to the Virus of St. Louis Encephalitis Inoculated Intracerebrally*

Age of mice	Dilutions of virus		
	$10^{-1}$	$10^{-2}$	$10^{-3}$
3 wks	(1)* 5† 5 5	4 4 5 5	4 4 5 5
6 wks	(1) 4 5 6	4 4 4 5	4 5 5 5
15 wks	4 4 4 5	4 4 5 5	4 4 5 5
3 wks.	4 4 4 5	4 5 5 5	5 S‡ S S
6 wks	4 5 5 6	4 5 5 6	5 S S S
15 wks	(1) (1) 4 5	5 5 5 6	5 5 S S
8 wks		5 5 6	7 S S
10 mos		5 6 6 6 6 9	9 12 18 S S S
14 days		4 4 5 5	4 4 6 S
8 wks.	4 4 5 5	5 5 5 5	5 6 S S

\* ( ) = death from unknown cause

† Numbers refer to day of death following inoculation

‡ S = survival of mouse.

TABLE II

*Susceptibility of Mice of Different Ages to the Virus of St. Louis Encephalitis Inoculated Intranasally*

Age of mice	Dilutions of virus		
	$10^{-1}$	$10^{-2}$	$10^{-3}$
3 wks	5 6 7 S	5 6 6 6	S S S S
6 wks	5 5 6 7	6 7 S	S S S S
15 wks.	5 6 6 7	6 6 6 7	7 S S S
3 wks.	6 6 7 7 7 9 S	(2) 6 7 8 8 10 S S	
6 wks	5 6 6 6 7 9 10 10	7 S S S S S	
15 wks	5 6 7 8 10 S S S	7 7 7 9 9 9 S S	
3 wks	6 6 7 7	6 S S S	S S S S
6 wks.	6 6 6 7	6 6 7 S	8 S S S
15 wks	6 6 7 S	6 7 7 S	7 S S S
10 mos.	6 6 7 7 7 7	7 7 8 8 S S	7 S S S S S

with dilutions of  $10^{-1}$  and  $10^{-2}$  of the virus, and an occasional mouse receiving either the  $10^{-1}$  or  $10^{-2}$  dilution died. In comparison with the mice 3 weeks

of age, those 2 weeks of age were much more susceptible to the virus when it was inoculated intraperitoneally, succumbing to dilutions of the virus as great as  $10^{-6}$

In summary these results indicate that no significant age difference in susceptibility is apparent in mice inoculated intracerebrally or intranasally, whereas mice inoculated intraperitoneally show increasing resistance with age, the most striking difference appearing between the 2nd and the 3rd week

TABLE III

*Susceptibility of Mice of Different Ages to the Intraperitoneal Inoculation of the Virus of St. Louis Encephalitis*

Age of mice	Dilutions of virus					
	$10^{-1}$	$10^{-2}$	$10^{-3}$	$10^{-4}$	$10^{-5}$	$10^{-6}$
3 wks.	3 3 3 3	3 6 6 7	5 15 5 5	9 5 5 5	—	—
6 wks.	3 6 3 8	5 6 6 8	5 6 5 5	—	—	—
15 wks.	6 3 3 3	5 5 5 5	5 5 5 5	—	—	—
3 wks.	4 4 3 3 3 3 7 5	4 3 3 3 6 6 6 6	5 8 8 3 3 5 5 5 5	—	—	—
6 wks.	3 4 6 10 3 3 3 3	3 7 5 5 5 5 5 5	—	—	—	—
15 wks.	5 6 10 3 3 3 3 3	—	—	—	—	—
2 wks.	4 3 3 3 3	3 6 6 7 5	6 7 5 5 5	8 8 9 9 3	8 8 9 9 3	6 8 10 10 5
3 mos.	6 6 3 3	3 3 3 3	5 5 5 5	—	—	—
2 wks.	—	—	5 6 6 6	7 8 8 8	6 8 10 3	8 8 11 3
2 wks.	—	4 4 4 3 3	4 4 4 3 6	7 9 10 11 12	8 8 15 5 5	7 8 8 15 5

### *Distribution of Lesions*

Webster and Fite (11, 12) and Smadel and Moore (13) described the histological changes produced by the virus of St. Louis encephalitis in mice inoculated intracerebrally, they emphasized the subpial and perivascular accumulations of mononuclear cells, foci of microglial proliferation about vessels, and beneath the pial membrane and necrosis of neurons. Webster and Clow (14) proved that virus instilled intranasally invaded the brain by the olfactory route. The presence of the virus in the olfactory bulbs was demonstrable 48 hours before the occurrence of the earliest lesions in that site.

The lesions which we have studied are, for the most part, the perivascular accumulations of cells and the mesodermal-glial response. Bodian and Howe (15, 16), studying experimental poliomyelitis in the monkey, demonstrated the feasibility of utilizing these lesions to follow the invasion of the C.N.S. by neurotropic viruses. After intranasal instillation of the virus of poliomyelitis, monkeys killed during the preparalytic stage of the disease showed lesions in the primary olfactory regions, and in the hypothalamic nuclei, the tegmentum of the mid brain and the reticular formation of the hind-brain,—centers con-



nected with the olfactory region by the olfactotegmental pathway. Certain centers not on this primary preferential pathway such as the amygdaloid nuclei, parolfactory and septal areas, pyriform cortex, and midline and dorso-medial thalamic nuclei, were also involved. In the late paralytic stage this pattern of distribution was not obscured but lesions were also found associated with the pathway between the motor cortex and the lower centers. In the late paralytic stage of the ascending infections, which followed inoculations into the sciatic nerve, peritoneal cavity or spinal cord, the distributions of lesions were similar to those observed following intranasal instillations, but as a rule lesions were more abundant in the reticular formation and tegmentum and diminished suddenly rostral to the region of Forel's fields. Lesions were absent from the olfactory bulbs, most of the other olfactory centers and the midline thalamic nuclei.

Because of the small size in the mouse brain references to cytoarchitectonic designations of many well known nuclei have been avoided where possible and the observations have been reported in the conventionally used gross descriptive terms. However, it has been convenient to divide the pyriform cortex into retrobulbar, prepyriform, and periamygdalar regions, and to mention the more caudally situated entorhine region from which the hippocampus receives abundant olfactory afferent fibers. The site and extent of each of these regions is given in the cytoarchitectonic atlas of Rose (17). In the present study, the dorsal thalamus has been divided into anterior, medial, and lateral areas. The medial area includes the midline as well as the medial nuclear groups, the lateral area contains the cortical relay nuclei. The anterior nuclei are not mentioned because they appear in relatively few sections. Considerations based on the blood supply of the thalamus of the rodent (Schlesinger, 18) indicate that further subdivision is inadvisable. The nuclear configuration of the tegmentum of the mid-brain and the reticular gray of the hind-brain is described and illustrated by Craigie (19).

*Intranasal Series*—Four groups totalling 35 mice 6 to 8 weeks of age received  $10^{-2}$  or  $10^{-4}$  dilutions of virus instilled nasally. The time of appearance of the clinical symptoms varied among the different groups with no constant relation to the dilution of the virus employed. Histologically it was found convenient to divide the series into early and late stages based upon the extent of invasion of the CNS.

In the early stage, lesions were localized primarily to the basal olfactory territory of the telencephalon and to centers associated with the olfactotegmental pathway leading from that territory to the mid- and hind brains. Five of the 24 brains removed before clinical signs of disease developed showed such localized lesions, 11 were entirely negative, and in the remainder the lesions were more widely distributed.

Webster and Cline (14) recorded perivascular accumulations of lymphocytes in the olfactory bulb as early as the 3rd day following intranasal instillation of the virus. We have confirmed this observation in one brain that was otherwise negative. In 4 other brains, obtained from animals killed upon the 4th and 5th days following

inoculation there was more extensive invasion of the C.N.S. Accumulations of cells were prominent about many vessels in the olfactory bulbs, and occasional foci of mesodermal glial proliferation were observed. The retrobulbar and prepyriform regions showed similar lesions. The peramygdalar region was involved to a lesser degree, but occasionally slight proliferation of microglia in its plexiform layer was also found. At this time lesions also appeared in the tubercula olfactoria septa, and ventral parts of the caudate nuclei. The latter appeared to have been invaded from the tubercula olfactoria and pyriform territory. Lesions were observed in the preoptic areas in all of these brains but in 2 of the 4 none were encountered caudal to this level. In the other 2 brains lesions were also observed in the hypothalamus, the medial areas of the dorsal thalamus, tegmentum of the mid brain and the dorsal part of the reticular gray at the rostral end of the hind brain. In addition there was usually a slight involvement of the frontopolar frontal interhemispheric, and temporal parts of the cortex which closely adjoin the basal olfactory territory.

An outstanding feature of the early stage was the constancy with which the lesions upon one side were more severe and abundant than upon the other. This difference was most obvious in the pyriform territories and tubercula olfactoria but also appeared in the caudate nuclei, dorsal thalamus and tegmentum. Differences between the two sides of the brain were also encountered in the intraperitoneal series other wise this result could be attributed to the amount of virus which entered one nostril as compared with that entering the other.

The lesions in the late stage were no longer confined to the primary olfactory centers and those associated with the pathway leading to the tegmentum and reticular formation. This more widespread distribution characterized the brains obtained from animals killed at the onset of clinical signs but was also observed in some of the brains obtained in the preclinical period. In the pyriform territory (Figs 1 and 2) and tubercula olfactoria the mesodermal-glial response was always more severe than that observed during the early stage. This response in the plexiform layer of the pyriform cortex usually diminished in intensity from the retrobulbar toward the entorhine region. In 2 specimens of the late stage widespread necrosis of nerve cells had occurred throughout the pyriform territory (Fig 3) but this was not accompanied by an unusually severe mesodermal-glial reaction. Lesions were also abundant elsewhere in the fore-brain although parts of the neocortex or one hippocampus sometimes escaped involvement. Lesions of the mid-brain occurred in the central gray and tectum as well as in the tegmentum. Lesions of the hind brain were either localized to the dorsal part of the reticular gray as observed in specimens in the early stage, or were scattered throughout the reticular formation to the caudal end of the medulla.

*Summary*—Following intranasal instillation an early stage of distribution of lesions can be recognized in which the primary olfactory centers and those associated with the olfactotegmental pathway are principally involved.

*Intraperitoneal Series*—Groups of mice of different ages (2, 3, 4 and 6 to 8 weeks) were inoculated intraperitoneally with different concentrations of virus (Table IV) and killed usually in groups of 3, at half day intervals from 2 days following inoculation until clinical signs of disease appeared. Significant enough differences in distribu-

butions of lesions did not appear between the brains of the 3, 4, and 6 to 8 week age groups to warrant separate presentation. Therefore they are reported as a unit followed by the findings in 2-week-old mice.

All brains and spinal cords of mice in the 3 to 8 week age group were negative until 3 days after inoculation. When  $10^{-1}$  dilution of virus was used, a limited distribution of lesions was found in at least 1 of each group of 3 brains obtained at that time, at intermediate periods (3 $\frac{1}{2}$  to 5 days) an increasing number of brains contained lesions, and at 5 to 6 days a majority of them. With  $10^{-2}$  and higher dilutions of virus a large majority of the brains including all those observed at the 3 day period were negative. Lesions did not appear until later and, compared with corresponding periods where  $10^{-1}$  dilution of virus was used, the distribution of lesions was frequently quite limited.

In 2 specimens of the 3 to 8 weeks age group convincing evidence was obtained that ascending invasion of the C N S occurs after intraperitoneal inoculation. Le-

TABLE IV

*Number of Mice of Different Ages Inoculated Intraperitoneally with Different Concentrations of Virus*

Age	Concentration of virus		
	$10^{-1}$	$10^{-2}$	Higher dilution
2	11	14	10
3	11		26
4	20	23	—
6-8	24	—	—

sions were found in the spinal cord and scattered through the reticular formation of the medulla. In one brain, the lesions disappeared in the hind-brain at the level of the nucleus of the VIIIth nerve, in the other, the tegmentum of the mid-brain was also involved and a group of lesions appeared in one lateral thalamic area and in the corresponding parietotemporal area of the neocortex. The lesions in the lateral thalamic area also extended toward the parafascicular nucleus which is situated in the medial thalamic area.

The majority of infected brains obtained at early and intermediate periods ( $10^{-1}$  dilution of virus) showed lesions which were scattered and mild in the pyriform territories, absent or very slight in the entorhine regions, hippocampi, and olfactory bulbs. The spinal cords were not invariably involved but lesions always appeared in the reticular formation at the caudal end of the hind brain. Rostrally in the hind brain, they were usually confined to the dorsal reticular gray. Lesions appeared in the tegmentum, central gray, and frequently in the tectum of the mid brain and in the lateral and medial areas of the dorsal thalamus. The hypothalamus, preoptic areas (Fig. 5), and tubercula olfactoria were also involved. In the latter region lesions were sometimes severe in contrast to the mild lesions usually observed in the pyriform territories. A variable part of the neocortex was frequently involved.

In other specimens obtained at the late periods, the spinal cords were always involved and the pyriform territories frequently showed extensive mesodermal-glial proliferation as well as perivascular accumulations of lymphocytes. Two of these brains showed widespread necrosis of nerve cells in the pyriform, periamygdalar and entorhine regions of one side. Lesions always appeared in the hippocampi, entorhine regions, and olfactory bulbs, and in the plexiform layer of the bulbs extensive proliferation of mesodermal glia has been observed.

Finally in another small but significant group of brains belonging to the 3 to 8 weeks age group, and not restricted to the younger of these mice, the distribution of lesions indicated that invasion had occurred by the olfactory route. The lesions in these brains were more advanced and abundant in the olfactory bulbs (Fig. 4) and pyriform territories as compared with those observed further caudally the spinal cords were almost always negative.

An isolated cluster of lesions widely separated from an obvious portal of entry occurred in only one brain (4-week-old,  $10^{-2}$  dilution of virus, 4th day). This was observed in the interior of the cerebellum.

In 2 week-old mice receiving a  $10^{-1}$  dilution of virus, lesions were distributed throughout the C.N.S. as early as  $2\frac{1}{2}$  days following inoculation. It was impossible to distinguish the portal of entry but the distribution of the lesions did not differ from those observed in older mice in the late stage in such a way as to suggest that the virus had involved the C.N.S. by the hematogenous route. Using  $10^{-2}$  dilution of virus the lesions did not appear until 3 days following inoculation but likewise involved the entire C.N.S. although they appeared more scattered than when the  $10^{-1}$  dilution of virus was used. Using still higher dilutions of virus the first appearance of lesions was retarded and a limited distribution similar to that obtained in the mice of the 3 to 8 weeks age group was obtained. One mouse killed on the 7th day following inoculation with a  $10^{-4}$  dilution of virus showed a limited distribution of lesions indicating that the virus had entered the brain by the olfactory portal. In another mouse which showed a flaccid paralysis upon the 7th day ( $10^{-4}$  dilution of virus), a typical ascending distribution of lesions occurred in which the fore brain was completely negative.

*Summary*—The results in all age groups indicate that the entire C.N.S. may be invaded by a virus which reaches it through the spinal cord and that this method of invasion probably occurs in the majority of mice inoculated intraperitoneally. However, a small but significant number of animals, irrespective of age, give decisive evidence of invasion of the C.N.S. by the olfactory route. Limited distributions of lesions do not occur in mice 2 weeks of age following intraperitoneal inoculation of  $10^{-1}$  or  $10^{-2}$  dilutions of virus, nevertheless they do occur when the virus is inoculated in higher dilutions.

#### DISCUSSION AND SUMMARY

The greatest change in the susceptibility of mice to the virus of St. Louis encephalitis inoculated intraperitoneally occurs between the 2nd and 3rd weeks of life. To investigate the mechanism of the influence of age on sus-

ceptibility, mice of different ages (2, 3, 4, and 6 to 8 weeks) were killed at intervals following intraperitoneal inoculation and the distribution of the lesions in the C N S was compared with that which resulted from infections via the nasal portal in mice 6 to 8 weeks of age.

Following intranasal instillation of the virus, lesions first appeared in the olfactory bulbs and advanced through the pyriform areas and the other fore-brain olfactory centers. Before the entorhine region and hippocampus were involved, lesions had already appeared in centers associated directly or indirectly with the olfactotegmental tract. The remainder of the C N S was more or less extensively involved in mice showing clinical signs of the disease.

In mice 2 weeks of age inoculated intraperitoneally with  $10^{-1}$  dilution of virus, lesions appeared throughout the C N S as early as  $2\frac{1}{2}$  days subsequent to inoculation, the virus spread so rapidly that the portal of entry could not be detected. The majority of the mice of the same age receiving  $10^{-2}$  to  $10^{-5}$  dilutions of virus and of the older mice receiving  $10^{-1}$  dilution of virus showed intermediate stages in the progression of lesions through the C N S. In the latter group this pointed to an ascending involvement in which the virus reached the fore-brain olfactory centers in retrograde fashion, the preoptic areas and tubercula olfactoria were extensively involved before the pyriform areas and olfactory bulbs. In another small but significant group of intraperitoneally inoculated mice representing all ages, lesions of restricted distribution occurred in the C N S which appeared in all respects identical with those which followed infection by the nasal route.

The significant difference in the susceptibility to infection between mice 2 weeks of age inoculated intraperitoneally and those 3 weeks of age or older inoculated by the same route is not readily explained by changes in the permeability of capillaries to the virus. It has been pointed out that in the 2-week-old mice ( $10^{-1}$  dilution of virus) the whole C N S was involved as early as  $2\frac{1}{2}$  days following intraperitoneal inoculation. However, the distribution of lesions did not differ materially from those observed when the C N S was completely involved in older mice killed at longer periods following inoculation. Therefore, the conclusion cannot be drawn that virus reaches the C N S of the 2-week-old mice directly through the blood stream while it reaches that of the mice 3 weeks of age and older by axonal pathways leading from the portal of entry. Our data strongly support the view that contamination of the nasal mucous membrane and subsequent invasion of the C N S by the olfactory route occurs not uncommonly in mice inoculated by peripheral routes (Sabin and Olitsky, 3), but we have observed no age difference in this respect for the virus of St. Louis encephalitis.

The C N S of the mouse during the first 2 weeks of life is still undergoing rapid changes leading to a complete neuronal and glial differentiation. In a critical discussion of the tectogenetic principle of cortical development Lorente

de N6 (20) has presented evidence concerning the stage of development attained by the entorhine cortex at intervals preceding and after birth. He observed that the migration of glial cells from the ependymal layer through the cortical plate began shortly before and was not finished until several days after birth, at 5 days glial cells had already entered the cortex and presented a very mature form, but other cells of the ependymal layer were still commencing their migration. Other evidence demonstrated that different kinds of neurones in the entorhine cortex could be recognized in their embryonic form at 12 hours subsequent to birth, at 5 days differentiation was more advanced in the deeper cortical layers but was still incomplete throughout. Definite information was not given concerning the age at which the glial and neuronal elements of the whole cortex become completely developed, but presumably it is considerably later than 5 days.

Therefore, the hypothesis that the mature C.N.S. is a less favorable substrate for the growth of neurotropic viruses than the immature one must be considered as a possible explanation for the greater susceptibility of 2 week-old mice to virus inoculated intraperitoneally. Reviewing the results obtained following intraperitoneal inoculation with the  $10^{-1}$  dilution of virus it is apparent that only in mice 2 weeks of age did the virus spread so rapidly through the C.N.S. that lesions could be detected everywhere as early as  $2\frac{1}{2}$  days subsequent to inoculation. In certain mice of the 6 to 8 weeks age group a restricted distribution of lesions was encountered at 3 and  $3\frac{1}{2}$  days, but it was not until later that the C.N.S. became completely involved. Also favoring the point of view that *tissue of the nervous system may vary in its ability to support the growth of the virus* is the fact that certain centers such as the entorhine regions, hippocampus, and neocortex may escape involvement in the mice 3 to 8 weeks of age killed at the early periods following inoculation.

On the other hand, the results obtained with the higher dilutions of virus ( $10^{-4}$  and  $10^{-5}$ ) in 2 week-old mice indicate that whatever difference may exist between the resistance of the immature and the mature nervous substrate must be only relative. Protracted incubation periods can occur and quite restricted distributions of lesions remain as late as 7 to 9 days following the inoculation of small amounts of virus. This observation, considered with the equal susceptibility of young and old mice to virus inoculated intracerebrally or instilled intranasally makes it seem unlikely that the greater susceptibility of young mice to virus inoculated intraperitoneally depends upon the immaturity of the tissue of the C.N.S.

All the observations point to the importance of the amount of virus reaching the C.N.S. following intraperitoneal inoculation. A possible explanation of the difference in susceptibility, as well as the early appearance of widespread lesions in the young animal receiving large amounts of virus, is that a greater amount of the virus inoculated intraperitoneally survives in the young animal

and reaches accessible portals of the C N S. The data are consistent with this explanation, as is the recent study of Morgan (21), who drew a parallel between the resistance of young vaccinated and adult normal mice to peripheral inoculation of the active virus of Eastern equine encephalomyelitis. The analogy drawn between young vaccinated mice and adults was based on the observation that, although susceptible to virus given by the intracerebral route, the young vaccinated animals, by the 4th day after the beginning of vaccination, resisted large doses of virus given by the intraperitoneal route. These results linked with the demonstration of the more rapid immune response of older animals to the virus of Eastern equine encephalomyelitis, as judged by the appearance of demonstrable neutralizing antibody (10), appear to offer an explanation for the greater resistance of older mice to the peripheral inoculation of active virus of Eastern equine encephalomyelitis.

The failure of some investigators (22) to demonstrate neutralizing antibody in the serum of mice immunized by the subcutaneous inoculation of active virus of St. Louis encephalitis until several weeks following the immunizing inoculation might seem to weaken the evidence for the immune response being involved in the resistance of mice to the peripheral inoculation of the virus of St. Louis encephalitis. However, recent observations by one of us (23) have shown that neutralizing antibody to the virus of St. Louis encephalitis can be demonstrated at least as early as one week (the earliest interval when tested) following the subcutaneous inoculation of mice over 3 weeks of age with active virus.

#### CONCLUSIONS

1. Young mice are more susceptible than older mice to the virus of St. Louis encephalitis inoculated intraperitoneally, but with virus inoculated intracerebrally or intranasally, there is no significant age difference in susceptibility. The greatest change in the resistance to the virus inoculated intraperitoneally occurs between the 2nd and 3rd weeks of life.

2. The distribution of the lesions of St. Louis encephalitis in the C N S of young and of old animals following intraperitoneal inoculation indicates that the virus may reach the brain either by the ascending pathway from the spinal cord or by the olfactory pathway irrespective of the age of the animal. However the ascending pathway is most frequently concerned.

3. The distribution of lesions does not offer evidence that the virus enters the C N S of young animals directly from the blood stream following intraperitoneal inoculation.

4. Although widespread lesions occur earlier in the C N S of young mice than in that of older mice inoculated intraperitoneally with large doses of virus, this fact is not satisfactorily explained by assuming the more rapid increase of the virus in the C N S of young animals, since the latter are not more susceptible to virus inoculated directly into the brain.

5 The observations can be explained by the hypothesis that a greater amount of virus survives and reaches the portals of the C.N.S. in young animals following intraperitoneal inoculation and that this is an important factor in the influence of age on susceptibility to the virus

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#### BIBLIOGRAPHY

- 1 Andervont, H. B., *J. Infect. Dis.*, 1929, 44, 383
- 2 Theiler, M., *Ann. Trop. Med. and Parasitol.*, 1930, 24, 249
- 3 Sabin, A. B., and Olitsky, P. K., *J. Exp. Med.*, 1937, 66, 35
- 4 Sabin, A. B., and Olitsky, P. K., *J. Exp. Med.*, 1937, 66, 15
- 5 King, L. S., *J. Exp. Med.*, 1940, 71, 107
- 6 Sabin, A. B., and Olitsky, P. K., *Proc. Soc. Exp. Biol. and Med.*, 1938, 38, 595
- 7 Sabin, A. B., and Olitsky, P. K., *Proc. Soc. Exp. Biol. and Med.*, 1938, 38, 597
- 8 Casals, J., *J. Exp. Med.*, 1940, 72, 445
- 9 Hurst, E. W., *J. Path. and Bact.*, 1936, 42, 271
- 10 Morgan, I. M., *Proc. Soc. Exp. Biol. and Med.*, 1940, 44, 473
- 11 Webster, L. T., and Fite, G. L., *Science*, 1933, 78, 463
- 12 Webster, L. T., and Fite, G. L., *J. Exp. Med.*, 1935, 61, 103
- 13 Smadel, J. E., and Moore, E., *Am. J. Path.*, 1934, 10, 827
- 14 Webster, L. T., and Clow, A. D., *J. Exp. Med.*, 1936, 63, 433
- 15 Bodian, D., and Howe, H. A., *Bull. Johns Hopkins Hosp.*, 1941, 68, 58
- 16 Bodian, D., and Howe, H. A., *Brain*, 1940, 63, 135
- 17 Rose, M., *J. Psychol. u. Neurol.*, 1930, 40, 1
- 18 Schlesinger, B., *J. Anat. and Physiol.*, 1941, 75, 176
- 19 Craigie, E. H., *Finer anatomy of the central nervous system based on that of the albino rat*, Philadelphia, Blakiston's Son and Co., 1925
- 20 Lorente de N6, R., *J. Psychol. u. Neurol.*, 1933, 45, 381
- 21 Morgan, I. M., *J. Exp. Med.*, 1941, 74, 115
- 22 Webster, L. T., *J. Exp. Med.*, 1938, 68, 111
- 23 Smith, M. G., to be published.



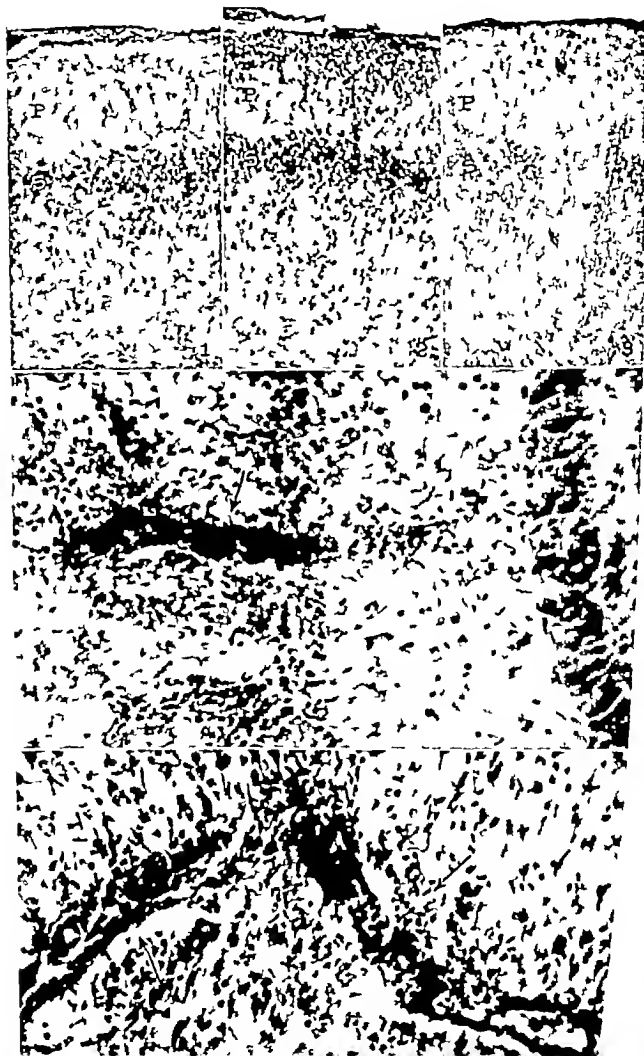
## EXPLANATION OF PLATE 4

FIGS 1 and 2 Subpial glial reaction in mice 6 weeks old receiving  $10^{-4}$  dilution of virus by nasal instillation. From the cortex of the pyriform lobe. *P*, plexiform layer, *S*, layer of superficial pyramids.  $\times 100$

FIG 3 Same area as represented in preceding figures. Illustrates a massive necrosis of nerve cells that followed nasal instillation of virus in a 6 week-old mouse, layers of superficial (*S*) and deep pyramids have been destroyed. This reaction was also observed in animals infected by the peritoneal route.  $\times 100$

FIG 4 Olfactory bulb of a 3 week-old mouse that received  $10^{-1}$  dilution of virus intraperitoneally and was killed  $3\frac{1}{2}$  days later. Note the accumulation of lymphocytes about penetrating vessels (arrow). No lesions were observed in this brain caudal to the preoptic area. Scattered vessels of the spinal cord were surrounded by accumulations of lymphocytes.  $\times 250$

FIG 5 Accumulation of lymphocytes (arrows) about vessels of the lateral preoptic area of a 6-week-old mouse that received  $10^{-1}$  dilution of virus by the peritoneal route and was killed  $4\frac{1}{2}$  days thereafter.  $\times 250$





STUDIES ON THE MECHANISM OF IMMUNITY IN TUBERCULOSIS  
THE FATE OF TUBERCLE BACILLI INGESTED BY MONONUCLEAR PHAGOCYTES  
DERIVED FROM NORMAL AND IMMUNIZED ANIMALS

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PLATES 5 AND 6

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The mechanism of the increased resistance to reinfection in tuberculosis is still uncertain. It has been demonstrated that bacilli of reinfection are either destroyed at once (1), if small numbers penetrate the tissues, or fail to multiply in the immune animal if large numbers invade the body (2), whereas in the normal individual the bacilli, whether many or few at first grow unhindered. As to the mechanism of this growth inhibition in the immune animal, it may be said that, while antibodies in low titer develop during the course of tuberculosis, there is no evidence of specific bacteriolytic agents acting *in vitro* (3). However, *in vivo*, studies have shown that in the body fluids of the immune animal the growth of tubercle bacilli is much less than that taking place in the body fluids of normal animals (2, 4). Since the bacillus multiplies not only in the tissue fluids but especially within the cytoplasm of the cells of the normal animal (5), the apparent failure of the microorganism to multiply within the phagocytes of the immune animal (6) must be explained.

The increased rapidity of the mobilization of mononuclear phagocytes at the site of invasion of the parasite, which characterizes the response of the immune as contrasted with that of the normal animal, has been recently shown to be a function of a heightened physiological activity conferred upon these cells by the tuberculous process (7). This results in an increased rate of cell division on the part of these phagocytes in response to the microorganism in the immune animal. Furthermore, this heightened physiological activity of the mononuclear phagocytes of the infected animal expresses itself by an increased phagocytic capacity for a variety of particulate substances such as carbon particles, staphylococci, and collodion particles. Tubercle bacilli are also more readily phagocytized *in vitro* by mononuclears derived from actively tuberculous animals than by those obtained from normal animals. This is independent of the menstruum of normal or immune serum in which they are suspended and is a property of the cells themselves. It is noteworthy that

this property is not significantly increased in animals vaccinated with an avirulent microorganism

Whether the observed failure of bacilli of reinfection to grow within the mononuclears of the tissues of the immune animal is also an expression of the altered physiological activity of these cells is the burden of the present study. It is obvious that mere increased phagocytosis of tubercle bacilli by "immune" phagocytes is no explanation for the failure of bacilli to grow within them. There is abundant phagocytosis of tubercle bacilli by the mononuclears of the normal animal (8) and it is precisely within the cytoplasm of normal phagocytes that the bacilli multiply.

Hanks and Brockenbrough (9) have recently reported that serum leukocyte mixtures from normal, infected, and immunized rabbits fail to show any bacteriocidal action on human tubercle bacilli *in vitro*. Rich (10) states that cells derived from immunized animals that ingest tubercle bacilli while growing in tissue culture fail to show a greater inhibitory effect on the multiplication of tubercle bacilli within them than cells derived from normal animals similarly cultivated.

Thus *in vitro* methods have failed to duplicate the inhibition of growth of bacilli that can be readily observed to occur in the living tissues of the reinfected animal. Since the bacteriostatic action of the body fluids of the immune animal cannot be demonstrated *in vitro*, but can be shown to occur by *in vivo* methods, it appeared possible that by *in vivo* methods one might demonstrate what appears to be the bacteriostatic effect of the cells on the growth of tubercle bacilli in the tissues of the reinfected animal. Greene (11), Luck (12), and others have recently used the anterior chamber of the eye of the living animal as a culture medium for the growth of living tumor cells. It appeared possible that this method might also be applied to the problem on hand.

All previous studies have indicated that, even with the highest degree of immunity attainable, the bacilli of reinfection are rarely, if ever, completely annihilated; at least a few bacilli always remain. It is obvious therefore, that quantitative methods must be used in order to answer the question whether within the cytoplasm of cells derived from immune animals tubercle bacilli are inhibited in their growth as compared to that taking place within the cytoplasm of phagocytes derived from normal animals.

It appeared desirable at first to test the efficacy of the *in vivo* method for the solution of this question under the most advantageous, rather than the most crucial conditions.

#### Methods and Materials

Normal and immunized rabbits were given a subcutaneous injection of human or bovine type tubercle bacilli suspended in salt solution containing India ink. The lymph nodes draining the site of injection, both in the normal and in the immunized

animal, were removed 2 days following the inoculation. Each lymph node was then divided into three portions: one was weighed, ground, and cultured, to determine the number of living bacilli it contained; an adjacent portion of each node was prepared for microscopic study; the third weighed portion of the lymph nodes, derived from the normal and the immunized animal, respectively, was cut up into fine particles with sharp scissors, washed several times in Tyrode solution, and injected into each anterior chamber of the eyes of a normal, non-tuberculous, albino rabbit previously treated with novocaine. The cells derived from the lymph node of the normal animal containing the bacilli and the carbon particles that had been carried to them by the lymph flow from the site of infection were placed in the anterior chamber of one eye. The cells derived from the lymph node of the immunized animal with their burden of tubercle bacilli and carbon particles originating at the site of reinfection, were placed in the same amount, in the anterior chamber of the opposite eye of the same albino host. In each instance the chamber fluid was first withdrawn by means of a 26 gauge needle, attached to a tuberculin syringe and inserted tangentially in the anterior chamber through the limbus of the cornea. Leaving the needle in place within the chamber, the syringe was removed and another tuberculin syringe containing the desired cell suspension, was attached and the suspension injected into the chamber in 0.1 to 0.2 cc. volumes.

The growth of the implanted cells was observed for a period of 10 to 14 days. At the end of this time the rabbit host was killed. Both eyeballs were removed and fastened with sterile push pins on sterile wooden squares. The fluid from each chamber was withdrawn into a syringe containing a suitable amount of 3 per cent sodium citrate or a heparin anticoagulating solution. This fluid, after microscopic examination, was appropriately diluted and cultured to determine the number of living tubercle bacilli it contained. The cornea was then removed by a circular incision. The entire iris and the ciliary body was then ablated from the underlying lens and vitreous humor, together with any growth which was attached to these structures. This tissue was now divided into three portions: one was examined microscopically by direct smear, the other was fixed for histological study and the third, constituting the major portion of these structures, was weighed, ground, and suspended in suitable amounts of fifteenth molar  $\text{Na}_2\text{HPO}_4$  and cultured to determine the number of tubercle bacilli which it contained.

Identical experiments were done with bone marrow obtained from normal and immunized animals respectively, that had received intravenously, 2 days previously, 0.1 to 10 mg. of human type tubercle bacilli mixed with India ink.

#### *Fate of Tubercle Bacilli Ingested in Vivo within Cells of Normal and Immunized Rabbits*

In this test the tubercle bacilli, both human and bovine, had been phagocytosed *in vivo* by cells of normal and immunized rabbits in the menstrium of their own body fluids. These normal and "immune" cells with their ingested tubercle bacilli and carbon particles were washed to remove adhering body fluids and transferred into the environment of the anterior chambers of a normal rabbit. Since the rabbit hosts were albinos, no pigment was present in

their irides or ciliary bodies and the cells implanted in the chambers could be identified by the carbon particles which they contained. A correlation was made of the growth of these implanted cells on or in the iris and ciliary body of the host rabbit, the bacilli which they contained, as seen in their microscopic sections, and the number of tubercle bacilli cultured from an adjacent portion of these structures. A comparison of the number of bacilli contained in the lymph nodes or in the bone marrow originally implanted in each anterior chamber with the number of bacilli cultured from the corresponding chamber fluid, the iris and ciliary body after 10 to 14 days incubation, gave an estimate of the relative inhibition or multiplication of the bacilli that had taken place in each chamber.

In Table Ia, are detailed the exact conditions under which each of 7 such experiments was done. The results obtained from these experiments are recorded in Table Ib.

It will be noted in Table Ib, in Experiments 4 to 7 inclusive, that the number of bacilli recovered from a unit weight of bone marrow obtained from immunized rabbits that had received an intravenous injection of 0.1 to 10 mg. of human type tubercle bacilli 2 days previously, was invariably greater than that cultured from the marrow of the normal animal similarly inoculated with the same amounts of the same suspension of tubercle bacilli (columns 2 and 6). Since the large numbers of bacilli injected have not been destroyed in the marrow of either animal, the greater numbers cultured from the immunized animal may be ascribed to the possibility that more bacilli had been removed by the bone marrow of the immunized animal from its circulation than had occurred in the normal animal. This would be in accord with the previously demonstrated fact that the phagocytic capacity of mononuclears of tuberculous animals for tubercle bacilli is greater than that of normal animals. The phagocytosis in the tuberculous animal is here further enhanced over that in the normal animal by the immune body fluids of the former.

Ten to 14 days after incubation of these marrows in the anterior chambers of a normal host, the iris and chamber fluid implanted with cells derived from the normal animal contained many more living bacilli than the same structures implanted with "immune" cells, despite the greater original number of bacilli contained in the "immune" implants. In the three remaining experiments, in which lymph node tissue of normal and immunized rabbits, containing either human or highly virulent bovine bacilli drained from subcutaneous foci of primary infection and of reinfection, respectively, was incubated in the anterior chambers of the same normal host, there were again much greater numbers of bacilli in the chamber implanted with cells of normal origin than in that implanted with cells of immune origin. In all of these 7 experiments the multiplication of the bacilli implanted together with normal cells was from 2 to 10 times as much as that of bacilli implanted in association with cells derived

TABLE I

*Fate of Tubercle Bacilli Ingested in Vivo within Cells of Normal and Immunized Rabbits Implanted in the Anterior Chamber of Normal Animals*

*(a) Conditions under Which Experiments Were Performed*

Ex- per- iment No	Tissue tested	Dose, type, and route of inoculation of bacilli	Mode of immunization of donor of immune cells and interval, in days between beginning of treatment and time of test	Days of incuba- tion of implanted tissue in anterior chamber
1	Axillary nodes	1.0 mg, human sub- cutaneously	0.1 mg human bacilli intravenously fol- lowed 1 mo. later by 0.2 mg and 1.0 mg. of the same strain intracutaneously and subcutaneously respectively 109	11
2	Popliteal nodes	4.0 mg bovine, sub- cutaneously	0.0001 mg virulent bovine bacilli intra- venously 84	14
3	Popliteal nodes	4.0 mg., bovine, sub- cutaneously	0.0001 mg virulent bovine bacilli intra- venously 95	14
4	Bone marrow	2.0 mg human intra- venously	Same mode of immunization as in Experi- ment 1 * 162	14
5	Bone marrow	0.1 mg human intra- venously	4.0 mg., human, subcutaneously 38	10
6	Bone marrow	0.4 mg., human intra- venously	1.0 mg, human intravenously 38	14
7	Bone marrow	10.0 mg human in- travenously	1.0 mg human bacilli intravenously fol- lowed 4 mos. later by 0.2 and 1.0 mg of the same strain intracutaneously and subcutaneously respectively 134	14

\* An additional 1.0 mg human bacilli given intravenously 15 days before test.

(b) Results Obtained

Ex- per- iment No.	Original No of colonies cultured from 100 mg of cells derived from normal animal	No. of colo- nies cultured from 100 mg of iris implanted with normal cells	No. of colonies cul- tured from 0.1 cc. of chamber fluid implanted with normal cells	Ratio between No of colonies cultured from iris and from cells originally implanted	Original No of colonies cultured from 100 mg cells derived from immunized animal	No. of colonies cul- tured from 100 mg of iris implanted with "immune" cells	No. of colonies cul- tured from 0.1 cc. of chamber fluid implanted with im- mune cells	Ratio between No of colonies cultured from iris and from cells originally implanted
1	5	202	1	40.40	6	28	0	4.66
2	5,360*	3,200	—	0.60	5,160*	1,700	55	0.33
3	39,000*	78,700	67,400	2.02	15,000*	4,300	7,100	0.28
4	872	41,800	2,730	47.93	1,118	14,900	64	13.33
5	960	20	0	0.02	1,790	20	0	0.01
6	9,470	8,300	672	0.88	25,740	1,900	408	0.07
7	59,800	66,000	2,950	1.10	91,800	16,100	1,450	0.17

\* Ravenel (bovine)

from an immune animal, both implants growing in identical environment in the two chambers of the same normal rabbit host (Compare column 3 with 7 and 5 with 9)



Microscopic examination of the iris implanted with cells of normal animals showed variable accumulations of intact, large mononuclears growing diffusely or in nodular formation on the surface or in the stroma of the iris. In the cytoplasm of these cells, which was often greatly developed and composed of large vacuoles, there were found large numbers of long, deeply and uniformly stained tubercle bacilli (Fig 1). These were frequently arranged in the form of strings or packets of parallel rods. In the cytoplasm of the same cells were seen variable amounts of carbon particles in varying degrees of dispersion. These particles as well as the bacilli were at times found in the form of a circle about the centrosphere of the cells. The mononuclears were intermixed with variable numbers of polymorphonuclear leukocytes in varying degree of preservation. At the periphery of these mononuclear growths mitotic figures were frequently encountered. There was a variable degree of accumulation of mononuclears without carbon particles in the stroma of the iris, apparently of host origin, which seemed to multiply in proportion to the multiplication of the bacilli in the implanted cells.

By contrast, in the opposite iris of the same host, implanted with cells of the immunized animal, the multiplication of the implanted cells was much less pronounced. The carbon particles within the cells were often more numerous and less dispersed. In these cells the bacilli were usually much fewer than in the cytoplasm of the implanted cells of normal origin. They were usually very short, faintly stained and often beaded (Fig 2). The cytoplasm of the implanted cells was characteristically finely vacuolated and, occasionally, typical mature epithelioid cells were seen. There was usually little polymorphonuclear infiltration of the explanted cells. The multiplication of the host cells was usually slight corresponding with the slight multiplication of the bacilli in the implanted "immune" cells.

On the iris implanted with bone marrow the growths frequently retained their original, natural structure with preservation of the fat spaces. However, in these explants the hemopoietic cells and most of the polymorphonuclears degenerated. Only the reticular cells with their burden of carbon particles and bacilli remained (Fig 2). In the iris implanted with lymph node tissue, plasma cells were encountered, presumably derived from the implanted lymphocytes.

By far the greatest number of bacilli seen in the chambers were within carbon-bearing, intact, living cells both in the iris and in the chamber fluid. Occasionally free, extracellular bacilli were encountered and some bacilli were seen in mononuclears not containing carbon. Most of the implanted cells whether derived from normal or immunized animals appeared well preserved and alive. Occasionally, however, necrobiotic cell collections were seen on the surface of the iris implanted with cells of both normal and immunized animals.

It is clear therefore that, while the bacilli cultured from the chamber fluid and the iris did not represent solely those contained within the implanted cells, there is no question but that most of the bacilli cultured were contained within the implanted cells. Therefore, it can be said with a reasonable degree of certainty that cells of immunized animals, that had ingested tubercle bacilli *in vivo* and had grown in the environment of the chamber fluid of a normal rabbit, greatly inhibited the multiplication of the microorganisms contained within them, as shown by comparison with the growth of similar bacilli ingested *in vivo* within cells of normal animals and incubated in the chamber fluid of the opposite eye of the same rabbit host. Whether the inhibitory effect of the "immune" cells on the growth of bacilli present in them is due to the properties of these cells themselves cannot be decided from this experiment. For it is conceivable that the greater inhibition of bacillary growth in these cells as compared with that in normal cells may be due to the film of immune body fluids that had coated the bacilli before their ingestion within the "immune" cells, for the bacilli that were contained within the normal cells were coated with normal body fluids before their phagocytosis. However it is plain from this experiment that no renewal of immune body fluids is necessary for the cells of immunized animals to continue to inhibit the growth of tubercle bacilli within them for 2 weeks after their transfer into the environment of a normal rabbit host.

#### *Fate of Tubercle Bacilli Ingested in Vitro within Cells of Normal and Immunized Rabbits*

In order to ascertain the rôle of the cells themselves and that of the immune body fluids of the immunized animal in the inhibition of growth of tubercle bacilli within them the ingestion of the microorganism must take place *in vitro* in the presence of both normal and immune serum, respectively. It must be first determined whether cells of normal origin will also inhibit the growth of tubercle bacilli within them if the phagocytosis of the bacteria takes place in a menstruum of immune serum. It must next be disclosed whether cells of immune origin will continue to inhibit the growth of the bacilli when the latter are ingested in the presence of normal serum. Finally, the relative inhibitory effect on the growth of tubercle bacilli must be estimated when cells of normal and immune origin both phagocyte the bacilli in a medium of immune serum. In all these three experiments it would be desirable to grow the cells with their ingested bacilli in the same type of body fluid in which the phagocytosis had taken place.

The following procedure was carried out. Normal or immunized rabbits received an intrapleural injection of about 15 cc. of a sterile 30 per cent acacia solution (13) containing 4.25 per cent sodium chloride. Two such preparations were employed, Lilly's and Endo's. Both are used clinically for intravenous injection after fivefold

dilution with distilled water. The rabbits received this material undiluted. Four to 5 days later the sterile exudate was withdrawn from each rabbit in a syringe containing a suitable amount of 0.4 per cent sodium citrate in 0.85 per cent sodium chloride (8). Both exudates were now centrifuged simultaneously at low speed for 4 to 6 minutes. The supernatant fluid was pipetted off and the cells were gently washed in 30 cc. of the citrated salt solution just mentioned, and again centrifuged. This washing was repeated three times in order to remove the body fluids in which the exudate cells were contained. The final cell sediment was then suspended in about 2 cc. of the citrated salt solution. Total and differential cell counts were made on each cell suspension. Both cell suspensions were then adjusted by proper dilution so as to contain the same number of mononuclears per cubic millimeter. The concentration of mononuclears in the various exudates varied to some extent. However, in the majority of instances, it constituted well over 75 per cent of the cells. The polymorphonuclears and the lymphocytes could not be equalized.

To 0.5 cc. of each cell suspension was added the same volume of fresh undiluted serum derived from the heart's blood of either the normal or the immunized donor of the exudate cells. The amount of serum added to the cells varied from 0.3 to 1.0 cc. in the different experiments. To each of these serum leukocyte mixtures was added the same amount of the same suspension of human type tubercle bacilli (P 15 B) containing India ink. The tubes were stoppered with sterilized corks coated with melted paraffine and rotated in the Robertson machine (8) in an incubator for 30 minutes at 37°C. to permit the phagocytosis of the tubercle bacilli and the carbon particles. At the end of this time the tubes were plunged into ice water to arrest phagocytosis and lightly centrifuged for 2 to 4 minutes. The supernatant fluid was removed as completely as possible in order to free the cell mixtures from unphagocytosed bacilli present therein. The number of living unphagocytosed tubercle bacilli present in the supernatant fluid was determined by culture.

To each cell sediment was now added 0.5 cc. of the same fresh normal or immune serum originally present in each phagocytic mixture. The chamber fluid from one eye was then withdrawn and one portion of the gently but thoroughly stirred cells with their proper serum fluid was injected into the emptied chamber, as previously described. The other cell suspension, containing the cell and serum combination to which the first was to be compared, was similarly injected into the opposite empty anterior chamber of the same albino rabbit host. From the remaining portions of each cell mixture smears were made on specially cleaned slides to determine the degree of phagocytosis of tubercle bacilli and carbon particles that had taken place *in vitro*. From the same portions of each cell mixture proper dilutions in fifteenth molar  $\text{NaH}_2\text{PO}_4$  were prepared and cultured on modified Lowenstein medium (14) to determine the number of living tubercle bacilli present in each cell mixture at the time of implantation into each anterior chamber.

The cells were thus incubated in the anterior chambers for 14 to 20 days. At the end of this time the number of bacilli present in each chamber fluid and in each iris was again determined by culture as outlined above. This was correlated with microscopic studies of the same tissues. As in the first experiment the implanted cells could be identified by their contained carbon particles. A comparison of the number of bacilli originally present in the cells implanted in each chamber with numbers

cultured from the corresponding chamber fluid and iris with its growing implanted tubercle bacilli-bearing cells after incubation, indicated the fate of the bacilli in the cytoplasm of each cell type. Since the chamber fluid was removed before the implantation of the cells and since each cell mixture thus introduced into each chamber was suspended in the same fresh serum in which the *in vitro* phagocytosis of the bacilli had taken place, it is clear that the implanted cells were exposed, for some time at least, to the same fluid medium in which the *in vitro* phagocytosis of the bacilli had occurred.

*Fate of Tubercle Bacilli Ingested in Vitro by Cells Derived from Normal Animals in the Presence of Normal and Immune Serum*—As stated above, in evaluating the rôle of the cells themselves and that of the immune body fluids in the inhibition of growth of tubercle bacilli in the cells of the reinfected animal, it must first be determined whether cells of normal origin will also inhibit the growth of the microorganism within them if their phagocytosis and growth takes place in a medium of immune serum. In Table II*b* are presented the results of 6 experiments in which the growth of tubercle bacilli ingested by normal cells in the presence of normal serum is compared to that of bacilli ingested by the same cells but in a medium of immune serum. The experiments were executed as just outlined and the detailed conditions under which these experiments were performed are recorded in Table II*a*.

Column 4 gives the mode of immunization of the donors of immune serum. It will be noted in columns 5 and 6 that the number of mononuclears per cubic millimeter in each of the phagocytic mixtures greatly exceeded the number of individual tubercle bacilli estimated to be present in the same volume. This estimate was based on the weight of bacilli suspended in a given volume of the phagocytic mixture in question. It was assumed that there were approximately 100,000,000 individual bacteria in 1 mg. of pure culture.

In the majority of instances the cell suspensions contained more than 85 per cent mononuclears. There was no constant increment in the phagocytosis of tubercle bacilli or carbon particles *in vitro* by the normal cells when their ingestion occurred in the presence of immune serum as compared with that taking place in normal serum. (These data are omitted from the table to save space.) In the majority of instances after phagocytosis fewer tubercle bacilli remained in the supernatant fluid of the mixture containing immune serum than in that containing normal serum. The difference however was slight and, in all but one instance, within the range of error of the experiment.

In Table II*b*, columns 2 and 6, it can be seen that there was no considerable, constant difference in the number of living bacilli present in the cells after ingestion of the microorganism *in vitro* in either serum at the time of their respective implantation in each chamber. After 14 to 15 days incubation of these normal cells in the chamber of each eye of the same rabbit there was no constant difference in the relative multiplication of the bacilli within the implanted cells in or on the iris, whether the original ingestion of the micro-

TABLE II

*Fate of Tubercle Bacilli Ingested in Vitro within Cells Derived from Normal Rabbits in the Presence of Normal and Immune Serum, Planted in the Anterior Chamber of Normal Animals*

(a) *Conditions under Which Experiments Were Performed*

Experiment No	Inflammatory irritant	Interval between introduction of irritant and withdrawal of exudate	Mode of immunization of donor of immune serum and interval in days between beginning of treatment and withdrawal of serum	No of mononuclears per c mm in phagocytic mixture	Estimated No of tubercle bacilli per c mm in phagocytic mixture	No of colonies in 100 c mm of supernatant fluid of phagocytic mixture containing		Incubation in anterior chamber
						Normal serum	Immune serum	
		days						days
1	Lilly's acacia and glycerol broth	4	0.0001 mg Ravenel intravenously, 116	41,000	3,600	1,040	700	14
2	Endo's acacia	4	Progressive bovine tuberculosis acquired by contact, 120*	29,000	1,500	3,520	4,630	14
3	Endo's acacia	4	0.1 mg human bacilli intravenously followed 1 mo later by 0.2 and 1.0 mg of the same strain intracutaneously and subcutaneously respectively, 47	—	1,500	3,580	2,100	14
4	Endo's acacia	4	Same mode of immunization as in Experiment 3, 53	24,000	1,400	26	13	14
5	Endo's acacia	4	Same mode of immunization as in Experiment 3, 59	21,000	1,500	53	53	15
6	Endo's acacia	5	Same mode of immunization as in Experiment 3, 108†	11,000	2,000	14,300	2,600	14

\* Animal received 0.01 mg bovine type bacilli 6 days before withdrawal of serum

† Animal received 0.001 mg bovine type bacilli 28 days before withdrawal of serum

(b) *Results Obtained*

Experiment No	Original No of colonies cultured from 100 mg of cells phagocytizing tubercle bacilli in the presence of normal serum	No of colonies cultured from 100 mg of cells implanted with cells phagocytizing tubercle bacilli in the presence of normal serum	No of colonies cultured from 0.1 cc of chamber fluid implanted with cells phagocytizing tubercle bacilli in the presence of normal serum	Ratio between the No of colonies in implanted iris and in originally implanted cells	No of colonies cultured from 100 mg of cells phagocytizing tubercle bacilli in the presence of immune serum	No of colonies cultured from 100 mg of iris implanted with normal cells phagocytizing tubercle bacilli in the presence of immune serum	No of colonies cultured from 0.1 cc of chamber fluid implanted with normal cells phagocytizing tubercle bacilli in the presence of immune serum	Ratio between the No of colonies cultured from implanted iris and from originally implanted cells
1	233,000	240,000	860	1.03	380,000	113,000	430	0.30
2	108,000	10,300	830	0.09	113,000	29,000	570	0.25
3	66,000	20,000	1,400	0.30	57,300	3,600	2,930	0.06
4	1,000	860	10	0.86	2,600	600	53	0.23
5	3,600	2,300	13	0.61	2,600	1,630	10	0.63
6	113,000	39,300	3,300	0.35	103,000	73,000	800	0.71

organism had taken place in a medium of normal or immune serum. Thus in Experiments 1, 3, and 4 the growth in the cells was 3 to 5 times less in the presence of immune than in the presence of normal serum (columns 5 and 9). In Experiment 5 the growth was the same in both and, in Experiments 2 and 6, the growth in immune serum was 2 to 3 times greater than that in normal serum (columns 5 and 9). Similar observations were made on the chamber fluid.

Microscopically there was usually little difference in the growth of the implanted cells and their contained bacilli in either iris. Their character was essentially the same as that described above for the growth of transplanted normal bone marrow or lymph node tissue that had ingested tubercle bacilli and carbon particles *in vitro*. In addition there was found in both chambers a fibrinous matrix attached to the iris in the meshes of which mononuclears bearing carbon and tubercle bacilli were present in diffuse or nodular growths intermixed with variable numbers of polymorphonuclears. Irrespective of whether the cells had originally ingested the bacilli in a menstruum of normal or immune serum, there was usually little difference in the number, size, shape, or staining characteristics of the bacilli within the implanted growing cells. In some instances, however, the number of bacilli visible within the cells that had ingested the microorganism in the presence of immune serum was less (Figs. 3 and 4).

It is clear that immune serum did not impart a constant inhibitory effect on the growth of tubercle bacilli within normal mononuclears when the ingestion of the microorganism took place in immune serum. The presence, for some indeterminate time of immune serum in the medium of growth of these normal phagocytes also failed to endow them with constant bacteriostatic properties.

*Fate of Tubercle Bacilli Ingested in Vitro by Cells Derived from Normal and Immunized Animals in the Presence of Normal Serum*—If the failure of the bacilli of reinfection to proliferate within the mononuclears of the tissues of the immunized animal is largely a property of the cells themselves it would follow that cells of immune origin that had ingested the microorganism in normal serum should also inhibit the growth of the phagocytized bacteria when subsequently grown on normal body fluids.

Accordingly the growth of tubercle bacilli ingested by cells of immunized rabbits in the presence of normal serum was compared to that of cells from normal animals that had ingested the microorganism in the same medium. These normal phagocytes that had ingested the bacilli and the carbon particles *in vitro*, suspended in normal serum, were planted in the emptied anterior chamber of one eye. The 'immune' phagocytes, with their similarly ingested carbon particles and bacilli, suspended in the same normal serum, were implanted in the emptied anterior chamber of the other eye of the same albino rabbit host. All the other measures involved were carried out as previously outlined.

In Table III *a* are given the conditions under which 5 such experiments were carried out. It may be mentioned that the cells and sera used in 5 of the preceding experiments were derived from the same animals as the cells and sera of the present 5 experiments. The original concentration of mononuclears in the pleural exudates of the normal animals varied between 30.1 to 89.5 per cent, that of the immune rabbits ranged between 63.5 and 95.0 per cent. Needless to say the percentage of mononuclears of both cell types was equalized before utilization for phagocytosis. The average phagocytosis of tubercle bacilli and carbon particles by cells of immune origin was greater than that of mononuclears of normal origin, as in previous experiments. However the number of living bacilli remaining in the supernatant fluid of the phagocytic mixture containing "immune" cells did not differ from that remaining in the supernatant fluid of the normal cell mixtures. Apparently the difference in the degree of phagocytosis between the normal and immune cells was insufficient to be detected by the number of bacilli remaining in their menstrua. It must be emphasized that these experiments were not set up for the purpose of determining the degree of phagocytosis. For this latter purpose the bacilli in the menstruum were too few, chance meeting of phagocyte and particle played too much of a rôle. The aim was to present so few bacilli for phagocytosis that even the normal cells would take up the bacilli in approximately the same numbers as the immune cells.

As seen in columns 2 and 6 of Table III *b* this goal was actually achieved in 4 out of the 5 experiments. For in these tests the number of viable bacilli in the normal phagocytic cells before implantation did not differ significantly from that contained in the "immune" cells. In these same experiments, the multiplication or rather the survival of the bacilli in the iris of the normal rabbit implanted with "immune" cells was from 5 to 12 times less than that of the iris implanted with normal cells, despite the fact that there was no immune serum in the medium in which either the ingestion of the bacilli or the growth of the phagocytic cells had taken place. Likewise in the majority of the chamber fluids implanted with "immune" cells there were much fewer bacilli after 14 to 15 days incubation than in the chamber fluid planted with normal cells. The single exception was Experiment 3 where the survival of the bacilli in the "immune" cells was greater than that in the normal phagocytes. It is interesting to note in this connection, that the normal and immunized donors of the cells of this experiment were subsequently infected with virulent tubercle bacilli. It was found that the normal rabbit showed greater resistance to tuberculosis than the immunized animal. The normal animal was a member of a naturally resistant family (15).

Microscopic examination of the growths of the implanted cells confirmed the observations previously detailed. The growth of the bacilli in the cells of

TABLE III

*Rate of Tubercle Bacilli Ingested in Vitro within Cells Derived from Normal and Immunized Rabbits in the Presence of Normal Serum Planted in the Anterior Chamber of Normal Animals*

(a) Conditions under Which Experiments Were Performed

Experiment No.	Inflammatory Irritant	Interval between introduction of irritant and withdrawal of exudate	Mode of immunization of donor of "immune" cells and serum and interval, in days, between beginning of treatment and withdrawal of serum and cells	No. of mononuclears per c. mm. in phagocytic mixture	Estimated number of tubercle bacilli per c. mm. in phagocytic mixture	Number of colonies in 100 c. mm. of supernatant fluid of phagocytic mixture containing:		Incubation in anterior chamber
						Normal cells	"Immune" cells	
		days						days
1	Endo s acacia	4	Progressive bovine tuberculosis acquired by contact 120*	29 000	1 500	1 310	1 880	14
2	Endo s acacia	4	0.1 mg human bacilli intravenously followed 1 mo later by 0.2 and 10 mg of the same strain intracutaneously and subcutaneously, respectively 47	—	1 500	4 540	3 010	14
3	Endo s acacia	5	Same mode of immunization as in Experiment 2 108†	11 000	2 100	7 000	8 600	14
4	Endo s acacia	4	Same mode of immunization as in Experiment 2, 53	24 000	1 400	90	90	14
5	Endo s acacia	4	Same mode of immunization as in Experiment 2 59	21 000	1 500	50	30	15

\* Animal received 0.01 mg bovine type bacilli 6 days before withdrawal of serum and cells.

† Animal received 0.001 mg bovine type bacilli 28 days before withdrawal of serum and cells.

(b) Results Obtained

Experiment No.	Original No. of colonies cultured from 100 mg. of normal cells phagocytizing tubercle bacilli	No. of colonies cultured from 100 mg. of iris implanted with normal cells	No. of colonies cultured from 0.1 cc. of chamber fluid implanted with normal cells	Ratio between the No. of colonies in iris and in originally implanted cells	Original No. of colonies cultured from 100 mg. of "immune" cells phagocytizing tubercle bacilli	No. of colonies cultured from 100 mg. of iris implanted with "immune" cells	No. of colonies cultured from 0.1 cc. of chamber fluid implanted with "immune" cells	Ratio between the No. of colonies in iris and in originally implanted cells
1	122 000	26 000	1 530	0.21	111 000	5 000	360	0.04
2	56 000	7 300	4 100	0.13	65 000	860	130	0.013
3	153 000	2 000	0	0.013	80 000	5 300	130	0.066
4	2 300	2 300	26	1.00	1 600	33	0	0.02
5	3 000	166	0	0.05	2 600	10	16	0.004

normal origin was greater in 4 out of the 5 experiments than that in the implanted cells of immune origin. In some of these the difference was very great.



The normal cells actually contained skeins of tubercle bacilli, deeply stained and long (Fig 5), while in the "immune" cells they were difficult to find and those seen were very short, poorly stained, and beaded (Fig 6). Furthermore the cytoplasm of the normal cells consisted of large irregular vacuoles. That of the "immune" cells was much finer and more regular. Typical mature epithelioid cells with differentiation of the cytoplasm into an external dark periphery and an internal lighter zone were also seen in the "immune" cells growing in or on the iris of the normal host.

It is plain therefore that cells obtained from an immunized animal, washed free of their immune body fluids, which had ingested tubercle bacilli *in vitro* in the presence of normal serum and had been planted and grown *in vivo* in the environment of a normal animal bathed either in the normal serum introduced into the chamber or in the natural chamber fluid, inhibited the growth of tubercle bacilli within their cytoplasm, an average of 10 times more effectively than cells of normal animals that had ingested the microorganism and had grown under identical conditions. This clearly indicates that the inhibition of growth of tubercle bacilli within the cells of the reinfected animal is a property chiefly of the phagocytic cells themselves and that immune body fluids and the organ environment of the immune animal are not essential for this function.

*Fate of Tubercle Bacilli Ingested in Vitro by Cells Derived from Normal and Immunized Animals in the Presence of Immune Serum*—It was found above that, while immune serum does not constantly impart a significant inhibitory effect on the growth of tubercle bacilli ingested by cells of normal origin, the immune sera of some immunized animals did apparently exercise such an effect, to some degree. It appeared desirable, therefore, to test further the rôle of the cells and sera by determining the relative inhibitory properties of both agents acting simultaneously. Accordingly the growth of tubercle bacilli ingested by cells of normal animals in the presence of immune serum was compared to that of bacilli ingested by cells of immune origin in the same medium.

It will be noted in column 4 of Table IV *a*, which details the conditions under which this series of experiments was performed, that all the donors of the "immune" cells and the immune sera used in this series had undergone progressive tuberculosis caused by the highly virulent bovine bacillus, Ravenel. At the time when these sera and cells were obtained, this tuberculosis had affected the donors for 44 days to one year. This was done in order to elicit a high immune state in these donors.

As in the previous series, the average phagocytosis of tubercle bacilli and carbon particles by the "immune" cells was greater than that by the normal cells. However, here too there was no constant difference in the number of

TABLE IV

*Fate of Tubercle Bacilli Ingested in Vitro within Cells Derived from Normal and Immunised Rabbits in the Presence of Immune Serum Planted in the Anterior Chamber of Normal Animals*

*(a) Conditions under Which Experiments Were Performed*

Experiment No	Inflammatory Irritant	Interval between introduction of irritant and withdrawal of exudate	Mode of immunisation of donor of "immune" cells and immune serum and interval, in days, between beginning of treatment and withdrawal of cells and serum	No. of mononucleated cells per c. mm. in phagocytic mixture	Estimated No. of tubercle bacilli per c. mm. in phagocytic mixture	No. of colonies cultured from 100 c. mm. of supernatant fluid of phagocytic mixture containing:		Incubation in anterior chamber
						Normal cells	"Immune" cells	
		days						days
1	Lilly's acacia and glycerine broth	4	0.001 mg. Ravenel intratracheally 44	58 000	590	500	130	14
2	Same as in Experiment 1	4	Progressive bovine tuberculosis 1 yr	23,000	140	530	430	20
3	Lilly's acacia	2*	0.001 mg. Ravenel intratracheally, 71†	—	140	250	706	14
4	Endo's acacia	4	0.05 mg. human type intravenously and 0.001 mg. Ravenel, by the same route 59 days later the serum and the exudate were withdrawn 58 days after the last injection 117	52 000	1 000	170	940	14
5	Endo's acacia	5	Same procedure as in Experiment 4 the serum and the exudate were withdrawn 70 days after the last injection 129	21 000	1 000	9 600	9 100	15
6	Endo's acacia	4	Same procedure as in Experiment 4 the serum and the exudate were withdrawn 78 days after the last injection 137	100 000	1,000	360	120	14

\* The exudate from the corresponding normal rabbit was withdrawn 4 days after injection of the irritant.

† This rabbit died with tuberculosis and snuffles pneumonia 2 days after the serum and exudate were obtained

*(b) Results Obtained*

Experiment No.	Original No. of colonies cultured from 100 mls. of normal cells phagocytizing tubercle bacilli in the presence of immune serum	No. of colonies cultured from 100 mls. of cells implanted with normal cells phagocytizing tubercle bacilli in the presence of immune serum	No. of colonies cultured from 0.1 cc. of chamber fluid implanted with normal cells phagocytizing tubercle bacilli in the presence of immune serum	Ratio between the No. of colonies in implanted cells and in originally implanted cells	No. of colonies cultured from 100 mls. of "immune" cells phagocytizing tubercle bacilli in the presence of immune serum	No. of colonies cultured from 100 mls. of cells implanted with "immune" cells phagocytizing tubercle bacilli in the presence of immune serum	No. of colonies cultured from 0.1 cc. of chamber fluid implanted with "immune" cells phagocytizing tubercle bacilli in the presence of immune serum	Ratio between the No. of colonies cultured from implanted cells and from originally implanted cells
1	28 000	22 000	160	0.80	31 000	2 300	16	0.07
2	8 800	15 100	500	1.70	8 600	2 400	230	0.28
3	35 000	3 000	126	0.09	60 000	34 000	1 440	0.57*
4	19 000	63 000	440	3.31	29 000	4 700	100	0.16
5	137 000	209 000	1 800	1.52	120 000	19 000	240	0.16
6	93 000	810 000	1 370	8.71	93 000	5 300	140	0.057

viable bacilli remaining in the supernatant fluid of either cell mixture after phagocytosis. Nor was there any significant difference in the number of living bacilli present in the normal and "immune" cells after phagocytosis in the same immune serum at the time of implantation of these cells in each chamber (Table IV b, columns 2 and 6). These normal and immune phagocytes, each containing approximately the same number of living bacilli and suspended in the same immune serum, were introduced into each emptied anterior chamber respectively of the same normal albino rabbit host.

Fourteen to 20 days later the growth of the bacilli in the normal cells, proliferating in a medium which, for a time at least, contained immune serum was, in 5 out of the 6 experiments, from 6 to 150 times as great as in cells derived from immune animals that had phagocytized the bacilli in the same immune serum and had grown in the same medium. Compare column 3 with 7 and 5 with 9. Likewise the chamber fluid implanted with cells of normal origin contained from 2 to 10 times as many living bacilli in these 5 experiments as the corresponding chamber fluid implanted with "immune" cells. In only one experiment, No. 3, were the results reversed. The donor of the "immune" cells and immune serum for this experiment had extensive snuffles pneumonia superadded upon his tuberculosis. This animal died 2 days after removal of its cells and serum for the test. It is possible that the intercurrent disease affected the immune state of this rabbit's cells and serum.

Microscopic examination of the irides with their implanted, carbon-bearing cells confirmed the cultural results and showed the same differences in the character of the growth of the two cell types and their contained bacilli as had previously been described in those experiments where cells of normal and immune origin were compared. These differences are illustrated in Figs. 7 and 8. The large numbers of the long tubercle bacilli in the cells of normal origin are contrasted with the single, very short bacillus seen in cells of immune origin. It is noteworthy that the carbon particles are in large masses in the cells of immune origin. They are much fewer and more dispersed in the cells of normal origin. Apparently the normal cells had greatly multiplied together with the multiplication of their contained bacilli and subdivided the burden of carbon, originally ingested *in vitro*, among the daughter cells. The "immune" cells, in which the bacilli not only failed to multiply but, as the cultures indicated, had been greatly reduced in number, proliferated but slightly and hence did not reduce the original carbon present in each cell at the time of implantation. Furthermore the normal mononuclears were intermixed with large numbers of polymorphonuclears. Many of the former had undergone injury from the large numbers of bacilli they contained and chemotactically attracted the granulocytes from the host. The "immune" cell growths on the other hand were not intermixed with polymorphonuclears. They were not injured,

as the bacilli had not grown in their cytoplasm, and hence exerted no chemotactic effect on the polymorphonuclears of the host's vessels.

It is thus again clearly shown that the inhibition of growth of tubercle bacilli by cells of the immune animal is a function of the cells themselves and that immune serum cannot impart to normal cells an equal inhibitory property for the multiplication of tubercle bacilli within their cytoplasm.

Essentially similar results were obtained in a few experiments with guinea pig cells and sera, using normal albino guinea pigs as hosts for the normal and immune cells that had phagocytized tubercle bacilli *in vitro* in normal or immune sera.

#### SUMMARY AND DISCUSSION

An endeavor was made to determine whether phagocytic mononuclears of immunized animals, removed from the influence of the organs in which they are naturally situated, will inhibit the growth of tubercle bacilli in their cytoplasm more effectively than similar cells obtained from normal animals. It was also undertaken to ascertain to what extent the inhibition of growth of tubercle bacilli in the immunized animal is due to the cells themselves and to what degree it is accounted for by the immune body fluids which bathe them. To answer these questions the anterior chambers of normal albino rabbits were used as *in vivo* incubators. One anterior chamber was host to one type of cell or cell-serum mixture, while the other anterior chamber of the same rabbit was host to a cell type or a cell-serum mixture to which the first was to be compared. The fate of the bacilli in each cell type and in each fluid menstruum was culturally determined by comparing the number of living bacilli present in the cells originally implanted with the number of bacilli that were contained in these cells after they had grown in the chambers. The implanted cells were identified by carbon particles that had been ingested by these cells at the same time that the bacilli were phagocytized.

It was found that cells of immunized animals, which had phagocytized tubercle bacilli *in vivo* in lymph nodes or bone marrow and had been transferred 2 days later into the environment of the chamber fluid of a normal rabbit, inhibited the growth of the microorganism within their living cytoplasm for 2 weeks in the absence of immune body fluids. Similarly transferred normal cells, under these conditions, permitted the bacilli to grow within them to a much greater extent. To what degree the inhibition of growth in these 'immune' cells was due to the immune body fluids which had formed a film about the bacteria before their phagocytosis or to the mere sojourn of the bacilli in these phagocytes in the body of the immune animal for 2 days before their transplantation to a normal environment could not be determined by these experiments.

To answer the latter question exudative mononuclears derived from normal

and immunized animals, washed free of their body fluids, were permitted to ingest tubercle bacilli and carbon particles *in vitro* in the serum of the normal or of the immunized donor of cells. Before incubating these phagocytes in the anterior chambers, the supernatant fluid of each phagocytic mixture was replaced by the same fresh serum in which the phagocytosis had taken place.

The presence of antibodies against the tubercle bacillus in the immune sera was not determined. It is certain however that in the tissues of such donors of "immune" cells and sera bacilli of reinfection fail to multiply, as had been abundantly demonstrated. It is not known how long the immune or normal serum introduced into the chambers with the phagocytic cells persisted there. It cannot be said with certainty therefore that implanted cells grew for the entire period of their sojourn in the chamber in the serum introduced with the cells. However, there is presumptive evidence to indicate that such introduced fluids remained in the chamber for a considerable time. It has been demonstrated by Seegal and Seegal (16) that protein antigens introduced into one anterior chamber sensitize the corresponding eye but not the opposite eye of the same rabbit. If proteins introduced into one chamber readily leave it there is no explanation for this phenomenon. Under these conditions, it was found that "immune" cells that had ingested tubercle bacilli *in vitro* in the presence of immune serum inhibited the growth of tubercle bacilli in their cytoplasm to a much greater extent than normal cells that had phagocytosed the bacteria in the same medium. Furthermore, the absence of immune serum in the medium of phagocytosis and growth of cells obtained from immunized animals did not rob them of their greater bacteriostatic properties on the growth of tubercle bacilli within them. Nor did the presence of immune serum during phagocytosis impart to cells of normal origin a significant and constant bacteriostatic effect.

It is clear therefore that "immune" phagocytic cells possess in themselves, apart from the immune body fluids, a greater bacteriostatic property on the growth of tubercle bacilli within them than do normal cells. This demonstration of the inherent bacteriostatic property of the "immune" cells is in harmony with the previously demonstrated increased capacity for phagocytosis of tubercle bacilli possessed by cells of actively tuberculous rabbits, which is also independent of the medium in which the phagocytosis takes place. It is significant that this enhancement of phagocytosis parallels the immunity of the possessor of such cells. Treatment of rabbits with tubercle bacilli of low virulence confers little immunity to the infection and little or no enhancement of the inherent phagocytic capacity of their cells for tubercle bacilli (7).

The demonstration by Moen and Swift (17) that mononuclears derived from animals sensitive to tuberculin retain that property even after several transplants in tissue culture, shows that allergy, the development of which is so

regularly associated with immunity, is also a property inherent in the cells themselves.

These results also support the conclusion drawn from many years' study on the fate of tubercle bacilli and the associated cellular responses in normal and immunized animals, namely, that the destruction or inhibition of multiplication of tubercle bacilli in the reinfected animals rests chiefly upon an increased capacity of the mononuclear phagocytes of the immunized animal to destroy or inhibit the growth of tubercle bacilli. The present study makes this conclusion more nearly certain. For, in the former studies it was found that the fate of the bacilli of primary infection or of reinfection is greatly dependent upon the organ in which they are focalized. Thus, when immunity develops in the course of a first infection, which had invaded all the organs simultaneously via the blood stream, the bacilli may be effectively destroyed in the liver, spleen, and bone marrow but not in the lung and kidney. It is conceivable that forces, apart from the inherent properties of the phagocytic cells that harbor the bacilli, resulting from the structures or functions of the organs and acting as environmental factors affect the behaviour of these cells and account for the observations. In the experiments here recorded it has been clearly demonstrated that immunity in tuberculosis is associated with an increased bacteriostatic property acquired by the mesenchyme cells in general that is independent of the organ environment in which the cells are situated, for it is also present outside of their influence.

To what extent immune body fluids can impart to normal cells increased bacteriostatic effects is not entirely answered by these experiments for there was no continuous renewal of immune body fluids in the medium of growth of the normal cells that were originally introduced into the chambers with immune serum. One especially hesitates to accept the inconstant results of this experiment in view of the fact that it has been clearly demonstrated that when bacilli situated extracellularly are continuously exposed to the body fluids of immune animals *in vivo* (2, 4) they are definitely inhibited in their growth by comparison to bacilli similarly exposed to normal body fluids.

#### CONCLUSIONS

1 Mononuclear phagocytes of immunized animals that had ingested tubercle bacilli *in vivo* and had subsequently been transplanted and grown in the environment of a normal animal continue to inhibit the multiplication of the microorganism in their cytoplasm in the absence of immune body fluids.

2 Mononuclear phagocytes of immunized animals that had ingested tubercle bacilli *in vitro* in the presence of immune serum inhibit the multiplication of the microorganism in their cytoplasm to a much greater extent than cells of

normal animals that had ingested the bacteria in the same medium and had grown in a similar environment

3 The presence of immune serum during the *in vitro* ingestion of tubercle bacilli by mononuclear phagocytes of normal animals does not regularly endow them with increased bacteriostatic properties for the microorganism. Whether or not continued sojourn of normal cells in immune body fluids will confer upon them such properties has not been determined.

4 Mononuclear phagocytes of immunized animals that had ingested tubercle bacilli *in vitro* in a medium of normal serum and had subsequently grown in an environment devoid of immune body fluids inhibit the multiplication of the microorganism in their cytoplasm to a much greater extent than do normal cells under the same conditions.

5 Active tuberculosis confers on the mononuclear phagocytes themselves increased bacteriostatic properties for the tubercle bacillus which are independent of the immune body fluids or of the organ environment in which they grow.<sup>1</sup>

#### BIBLIOGRAPHY

- 1 Lurie, M. B., *J. Exp. Med.*, 1929, 50, 747
- 2 Lurie, M. B., *J. Exp. Med.*, 1936, 63, 923
- 3 Romer, P. H., and Joseph K., *Beitr. Klin. Tuberk.*, 1910, 17, 365
- 4 Lurie, M. B., *J. Exp. Med.*, 1939, 69, 555
- 5 Lurie, M. B., *J. Exp. Med.*, 1932, 55, 31
- 6 Lurie, M. B., *J. Exp. Med.*, 1933, 57, 181
- 7 Lurie, M. B., *J. Exp. Med.*, 1939, 69, 579
- 8 Lucké, B. M., Strumia, M., Mudd, S., and McCutcheon, E. B., *J. Immunol.* 1933, 24, 455, 493
- 9 Hanks, J. H., and Brockenbrough, E., *Am. Rev. Tuberc.*, 1940, 41, 605
- 10 Rich, A. R., and McCordock, H. A., *Bull. Johns Hopkins Hosp.*, 1929, 44, 273
- 11 Greene, H. S. N., and Saxton, J. A., Jr., *J. Exp. Med.*, 1938, 67, 691
- 12 Lucké, B., and Schlumberger, H., *J. Exp. Med.*, 1940, 72, 321
- 13 Robertson, O. H., and Van Sant, H., *J. Immunol.*, 1939, 37, 571
- 14 Lurie, M. B., *J. Exp. Med.*, 1934, 60, 163
- 15 Lurie, M. B., *Am. Rev. Tuberc.*, 1941, 44, suppl., 1

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<sup>1</sup> Preliminary reports of the present work were presented before the Eastern Pennsylvania Chapter of the American Society of Bacteriologists on Nov. 28, 1939 (*J. Bact.*, 1940, 39, 339) and before the American Association of Pathologists and Bacteriologists, April 10, 1941 (*Am. J. Path.*, 1941, 17, 636). Since its completion Kallós (18) has published qualitative tissue culture studies confirming these quantitative results.

- 16 Seegal, D , and Seegal, B C., *J Exp Med* , 1931, 54, 249
- 17 Moen, J K. and Swift, H. K., *J Exp Med* , 1936, 64, 339
- 18 Kallós, P , *Beiträge zur Immunbiologie der Tuberkulose*, Stockholm, Ab Hasse  
W Tulbergs Förlag 1941



## EXPLANATION OF PLATES

All microphotographs were prepared from tissues stained by the Ziehl-Neelsen method and counterstained with hematoxylin. The magnifications are about  $\times 1400$ .

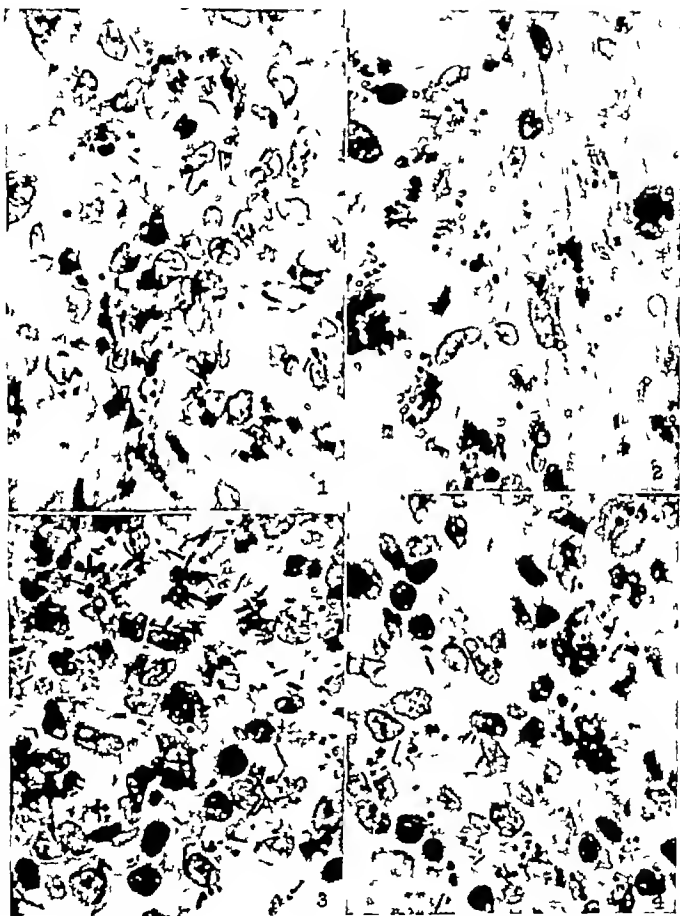
## PLATE 5

FIG 1 Bone marrow of normal rabbit, the reticular cells of which had ingested tubercle bacilli and carbon particles *in vivo*, growing in the anterior chamber of the eye of a normal rabbit (Experiment 7, Table Ib). 59,800 colonies were cultured from 100 mg of this tissue at the time of implantation. After 14 days incubation, 66,000 colonies were cultured from 100 mg of implanted iris. Ratio between the number of colonies in iris and that in the original inoculum, 1.1. Rapidly and diffusely growing mononuclears containing carbon particles and numerous, long, well stained tubercle bacilli in their cytoplasm.

FIG 2 Bone marrow of immunized rabbit, the reticular cells of which had ingested tubercle bacilli and carbon particles *in vivo*, growing in the opposite anterior chamber of the same host that harbored the normal cells shown in Fig 1. 91,800 colonies were cultured from 100 mg of this tissue at the time of implantation. After 14 days incubation, 16,100 colonies were cultured from 100 mg of implanted iris. Ratio between the number of colonies in iris and that in original inoculum, 0.17. The reticular cells of the surviving marrow contain carbon particles, one such cell, at the left margin of the photograph below its center, contains a mass of such particles. The original fat spaces of the marrow are retained and may be seen in the lower left and both upper corners of the microphotograph. Tubercle bacilli are very rare. Two microorganisms, poorly stained and short, are seen lying at an obtuse angle to each other near the right margin of the photograph, at about its center.

FIG 3 Phagocytic mononuclears of a normal animal, that had ingested tubercle bacilli and carbon particles *in vitro* in the presence of normal serum, growing in the anterior chamber of a normal host (Experiment 1, Table IIb). 233,000 colonies were cultured from 100 mg of cells at the time of implantation. After 14 days incubation, 240,000 were cultured from 100 mg of implanted iris. Ratio between the number of colonies in iris and in the original inoculum, 1.03. Diffusely growing, carbon-containing, mononuclears swarming with long, deeply stained, tubercle bacilli.

FIG 4 Phagocytic mononuclears from the same normal animal, as those shown in Fig 3 that had ingested tubercle bacilli and carbon particles *in vitro* in the presence of immune serum growing in the opposite anterior chamber of the same normal host that harbored the cells shown in Fig 3. 380,000 colonies were cultured from 100 mg of cells at the time of implantation. After 14 days incubation, 113,000 colonies were cultured from 100 mg of implanted iris. Ratio between the number of colonies in iris and in the original inoculum, 0.30. Diffusely growing, carbon-containing mononuclears with fewer and less well stained tubercle bacilli in their cytoplasm than those shown in Fig 3.



(Lurie Mechanism of immunity in tuberculosis)

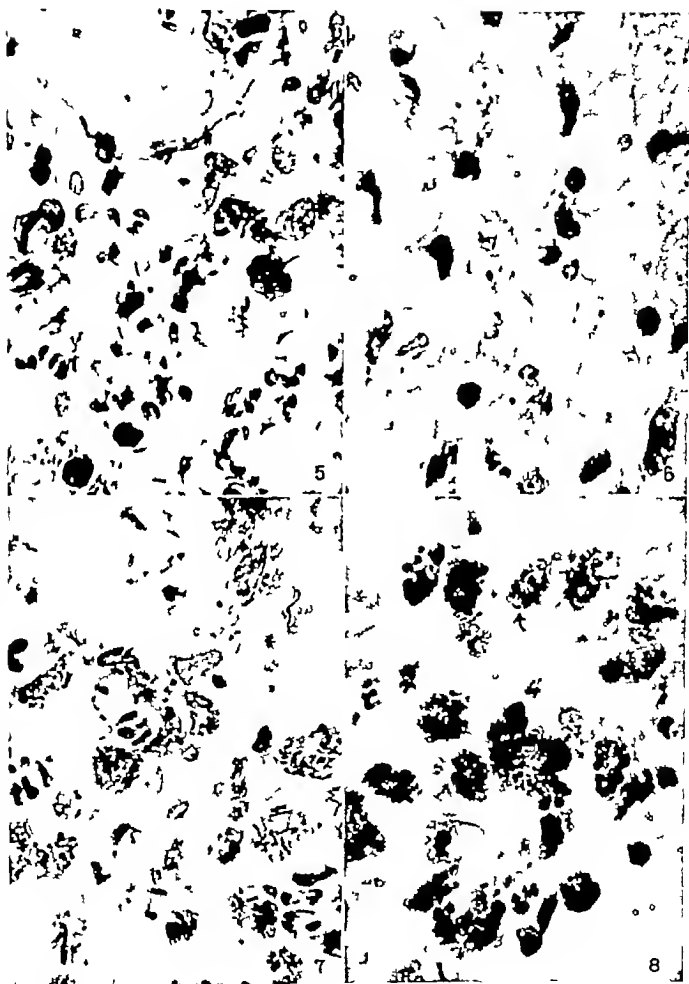
## PLATE 6

FIG 5 Phagocytic mononuclears from a normal animal that had ingested tubercle bacilli and carbon particles *in vitro* in the presence of normal serum, growing in the anterior chamber of a normal host (Experiment 2, Table III b) 56,000 colonies were cultured from 100 mg of cells at the time of implantation After 14 days incubation, 7,300 colonies were cultured from 100 mg of implanted iris Ratio between the number of colonies in iris and in original inoculum, 0.13 Large mononuclears with large vacuoles in their carbon-containing cytoplasm, infiltrated with necrotic polymorphonuclear leukocytes The bacilli are numerous Two large skeins of bacilli, one of which is U shaped, can be seen in the mononuclears near the left margin of the microphotograph at about its center

FIG 6 Phagocytic mononuclears from an immunized animal, that had ingested tubercle bacilli and carbon particles in the presence of normal serum, growing in the opposite anterior chamber of the same normal host that harbored the cells shown in Fig 5 65,000 colonies were cultured from 100 mg of cells at the time of implantation After 14 days incubation, 860 colonies were cultured from 100 mg of implanted iris Ratio between the number of colonies in iris and in original inoculum, 0.013 There are large mononuclears with very small round vacuoles, some containing carbon particles with a structure characteristic of epithelioid cells Such a cell, with a peripheral dark staining and a central light staining cytoplasmic zone, is seen near the left of the photograph at about its center In the cytoplasm of a cell below the former one can see a very short, diploid tubercle bacillus, the only one that could be found in this field There are no infiltrating polymorphonuclears

FIG 7 Phagocytic mononuclears from a normal animal, that had phagocytized tubercle bacilli and carbon particles *in vitro* in the presence of immune serum, growing in the anterior chamber of a normal host (Experiment 6, Table IV b) 93,000 colonies were cultured from 100 mg of cells at the time of implantation After 14 days incubation, 810,000 colonies were cultured from 100 mg of implanted iris Ratio between the number of colonies in iris and in original inoculum, 8.71 Mononuclears, infiltrated with and phagocytizing polymorphonuclears containing numerous tubercle bacilli and dispersed carbon particles in their cytoplasm are seen

FIG 8 Phagocytic mononuclears from an immunized animal, that had ingested tubercle bacilli and carbon particles *in vitro* in the presence of the same immune serum in which were suspended the normal cells shown in Fig 7, growing in the opposite anterior chamber of the same normal host that harbored the normal cells also shown in Fig 7 93,000 colonies were cultured from 100 mg of cells at the time of implantation After 14 days incubation, 5,300 colonies were cultured from 100 mg of implanted iris Ratio between the number of colonies in iris and in original inoculum, 0.057 Large mononuclears, heavily laden with masses of agglutinated carbon particles in their cytoplasm may be seen Tubercle bacilli are very difficult to find One very short, comma shaped bacillus, indicated by the arrow, can be seen in the cytoplasm of the cell near the upper right corner of the photograph just below the oval mass of carbon particles



(Lurie Mechanism of Immunity in tuberculosis)



# SEROLOGICAL REACTIVITY OF HYDROLYTIC PRODUCTS FROM SILK

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It has been briefly reported that precipitin reactions of antisera produced with heteroproteose are inhibited by peptic proteoses, small enough in molecular size to pass collodion membranes (1, 2). The purpose of these investigations was to get information on the smallest portions of a protein molecule that still are capable of specifically combining with antibodies and, finally, on the chemical structure of these determinant groups, questions as yet undecided. In resuming this line of work split products of silk, chosen as an example of a fibrous protein with a comparatively simple amino acid make-up, were examined and again inhibition reactions were observed with substances resulting from enzymatic digestion of this protein (see Bergmann and Niemann, 3). It was further seen that such reactions are obtained also with products of acid hydrolysis.<sup>1</sup>

The preparation of antisera for silk presented some difficulty at first but on injection of silk, dissolved with the aid of acid and after neutralization adsorbed onto charcoal immune sera were obtained (4a). An attempt with the method briefly mentioned by Fell (4b) was unsuccessful.

## Methods and Materials

*Immunization*—6 gm. of degummed silk were dissolved by stirring for about 4 minutes in 60 cc. concentrated hydrochloric acid and the solution diluted with 10 volumes of water. The solution was neutralized to weak acid reaction to Congo red with 10 per cent NaOH added in portions to avoid too high a temperature. The solid material which separates was allowed to settle and the supernatant fluid syphoned off. The sediment was washed by suspending in a large volume of water and after settling was centrifuged for a short time—at very low speed to prevent the formation of clumps that subsequently would be difficult to bring into solution. The precipitate was then taken up in 45 cc. of water and dissolved by adding dropwise dilute NaOH while stirring, avoiding an excess. The solution was brought back with dilute HCl to weakly alkaline litmus reaction.<sup>2</sup> This solution was used for the sero-

<sup>1</sup> This observation was made in our laboratory by Dr. R. F. Clutton.

<sup>2</sup> An electrophoretic experiment was kindly carried out by Dr. L. G. Longworth. The opalescence of the solution interfered with the observation but the material seemed to be homogeneous and had a mobility of  $-1.8 \times 10^{-5}$  cm./sec./volt/cm. in 1 per cent solution in phosphate buffer of 0.1 ionic strength and pH 8.0.

logical tests and for immunization after adsorption to blood charcoal. The charcoal was washed several times with water, dried, sterilized, suspended in saline solution, and thoroughly mixed with the silk solution, using 45 gm of charcoal for the solution made from 12 gm of silk (for preservation 0.5 per cent phenol was added). Immunization was carried out by repeated intraperitoneal injection of rabbits, each receiving at 5 day intervals 15 cc of a 6 fold dilution of the suspension in saline, a dose containing about 25 mg of silk and 0.35 gm charcoal. Sera of moderate strength were obtained after 6 to 12 injections.

*Hydrolysis and Fractionation*<sup>3</sup>—200 gm portions of degummed silk were dissolved, with stirring, in 1 liter of 50 per cent (by volume) sulfuric acid, and the solution was allowed to stand at 26–30°C for 4 hours. 2 liters of water were added, the solution (for convenience) kept overnight in the ice box and then dialyzed in cellophane tubing against running water for 3 hours. The remaining sulfuric acid was then removed with barium carbonate, in later runs with barium hydroxide, and any excess of barium was subsequently removed with sulfuric acid. The barium sulfate was filtered off on Buchner funnels and washed with boiling water. The combined filtrates and washings were evaporated in small portions on the steam bath to a small volume, the reaction during evaporation being kept slightly acid to litmus. The syrupy solution was placed in cellophane tubes and dialyzed in the ice box against 2 volumes distilled water with changes of water at the intervals stated. The outer fluids were evaporated in small portions on the steam bath, and finally were precipitated with acetone, filtered, and dried. The first three diffusates, after dialysis for 3, then 5, then 7 days, were combined. Yield 1200 gm from 4800 gm silk used. (The materials obtained on further dialysis are not considered in the following, also, in the description of the fractionation procedures only those substances are taken account of that were selected for use in the serological tests presented.)

The substance was boiled up with 2400 cc of water, cooled to room temperature, and a little toluene added as a preservative. After standing overnight at room temperature an insoluble portion was removed from the solution (A). This sediment was again extracted with water as above (solution B). To solution A 1½ volumes of alcohol were added and the mixture kept in the ice box for 48 hours. The resulting precipitate was filtered in the cold, washed with acetone, and dried<sup>4</sup>. From the filtrate a 2nd fraction was obtained by addition of 1/5 volume of alcohol (A<sub>1</sub>, 102 gm). The supernatant was evaporated to a small volume and precipitated with acetone (A<sub>2</sub>, 350 gm). Solution B was precipitated with 2 volumes of alcohol (precipitate B<sub>1</sub>, 35 gm). A second precipitate was obtained by adding 3 volumes of alcohol and the supernatant fluid was evaporated to a small volume and precipitated with acetone (B<sub>2</sub>, 100 gm). A<sub>1</sub> was further fractionated by successive addition of 1, 1/2, and

<sup>3</sup> In studies on the production of silk hydrolysis several dipeptides and a tripeptide (alanylglycyltyrosine) have been isolated in pure state (cf 3). A number of other split products have been described (5, 6).

<sup>4</sup> The same procedures—dissolving in 2 volumes of water except when stated otherwise, precipitation, drying, were followed in the other fractionations. The volumes of alcohol used in the fractionation are given in terms of the volume of the original aqueous solutions.

1 volume of alcohol and the last precipitate (11 gm) was similarly refractionated with  $\frac{1}{2}$ ,  $\frac{1}{2}$  and  $\frac{1}{4}$  volume of alcohol. The 3rd fraction is designated as preparation I.

A<sub>2</sub> and B<sub>2</sub> were joined, dissolved and the solution precipitated with 3 volumes alcohol; the precipitate (86 gm) was dissolved in 3 volumes of water and again precipitated with  $\frac{1}{4}$  volumes of alcohol. This substance (35 gm) dissolved in 4 volumes of water was separated into fractions which precipitated with  $\frac{3}{4}$ , 1, 2 and 3 volumes alcohol. The last of these fractions, preparation II, amounted to 1.5 gm.

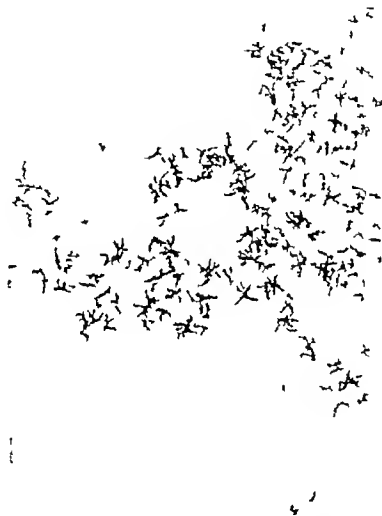


FIG. 1. Substance II from hydrolysis products of silk fibroin.  $\times 240$

The precipitate B<sub>1</sub> was redissolved in 6 volumes of water and precipitated with an equal volume of alcohol (preparation III, 7 gm).

A number of serologically active preparations were analyzed for total nitrogen and amino nitrogen in order to obtain estimates of the molecular size. The nitrogen analyses were made by the gasometric Kjeldahl method according to Van Slyke (with a modification devised by Goodner<sup>5</sup>). The amino nitrogen determinations were made by the Sørensen method using glass electrode measurements instead of indicators.

<sup>5</sup> Personal communication.



Glycine was determined with nitranilic acid (7), tyrosine by Bernhart's technique (8), and serine and alanine by the method of Fromageot and Heitz as modified by Desnuelle (9) (Deamination followed by oxidation and colorimetric determination of acetaldehyde)

*Substances Tested*—Substance I had microscopically a crystalline appearance (similar to that shown in Fig 1) when separating in the cold from solution in dilute alcohol. It contained 17.34 per cent N, 2.47 per cent  $\text{NH}_2\text{-N}$ , which would correspond to peptides with seven amino acids and with molecular weights of about 600. The ash was 1.9 per cent, containing a considerable proportion of Ca and  $\text{SO}_4$ . To obtain an indication of the degree of homogeneity, the material was dialyzed in a cellophane bag against small volumes of water, the outer fluid being removed, and replaced after 18, 47, 90, and 138 hours. The ratio of total N to amino N was 9 in the final inner fluid which contained only 4 per cent of the starting substance and varied from 7.3 in the first to 8.1 in the last diffusate. That the molecular weight values of the fractions (about 580 to 640) calculated from the amino N are of the correct order of magnitude was confirmed by determination of the freezing point depression (made with the second diffusate) which gave even a lower value, but since complete analytical data are lacking an accurate correction for salt (ash 2.9 per cent) was not possible.

Substance II had likewise a crystalline appearance, as shown in Fig 1. However, an x-ray picture failed to give definite evidence for crystalline structure.<sup>6</sup> On analysis 17.76 per cent N, 2.26 per cent amino N, (and 2.57 per cent ash) were found indicating octapeptides. Analyses for amino acids gave 48.8 per cent glycine, 35.6 per cent alanine, and 1.2 to 1.3 per cent tyrosine, the latter probably ascribable to some peptide present in small quantity.

Substance III separated from the solution in the form of shiny balls as seen microscopically. Analysis showed 18.11 per cent N, 1.53 per cent amino N, and 0.79 per cent ash, pointing to peptides with a chain length of 12 amino acids.

#### FINDINGS

The preparations just described were tested serologically by inhibition reactions (Table I).

It is seen that all three substances inhibited the precipitation of silk antigen by the antisera though to somewhat different degrees. (Still other fractions gave positive reactions likewise but were not further studied.) The strongest inhibition was obtained with substance III which from the analytical results appeared to have the largest molecular size. The specificity of the reaction was shown by tests, given in Table II, with several heterologous antiprotein sera and their corresponding antigens in which also a higher concentration of the substances was used. In order to determine whether the activity of

<sup>6</sup> Strong reflections were observed corresponding to 4.67 and 4.15 Å  $\mu$  and a weak reflection at about 3.7, but they may be due to the ash content. For this examination I am indebted to Dr. I. Fankuchen.

TABLE I

To 0.2 cc. of a 1:10,000 silk solution were added 0.05 cc. of solutions of the substances tested for inhibition and then 2 drops of immune serum

Readings were taken after 15 minutes at room temperature (1st line) and after 1 hour (2nd line)

Solution tested for inhibition	Substance I	Substance II	Substance III	Control
<i>per cent</i>				
1	0 0	0 0	0 0	± +
1/2	f tr tr	f tr tr	0 f tr	
1/4	tr ±	tr ±	f tr f tr	
1/8	(±) +	(±) +	tr ±	

The intensity of the reactions is indicated as follows: 0 f tr (faint trace) tr (trace) tr (strong trace) ±, +, ++, +++

TABLE II

Test as in Table I using 1 drop of the suitably diluted immune sera and the respective homologous antigens in a concentration of 1/10,000

Readings were taken after 1 hour at room temperature.

Immune sera against	Substance II		Substance III		Control
	1 per cent	2 per cent	1 per cent	2 per cent	
Chicken ovalbumin No I diluted 1:3	±	±	±	±	±
No II diluted 1:2	++	++	++	++	++
Horse globulin No I diluted 1:3	+	+	+	+	+
No II undiluted	+	+	+	+	+

preparation III might be due to a substance of high molecular weight, a diffusion experiment was carried out in the following manner

6 gm of the substance were dissolved in 10 volumes of water by heating, cooled to room temperature, and some undissolved material (0.315 gm) filtered off. The solution was placed in a cellophane bag and dialyzed in the ice box against 1½ volumes of water which was changed at the intervals stated. The diffusates were evaporated to a small volume and precipitated with acetone.

	Taken after	Weight	Total N	Amino N	$\frac{N}{\text{Amino N}}$
	<i>hrs</i>	<i>gm</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
1st diffusate	18	2.2	17.54	1.67	10.5
2nd "	24	1.44	17.78	1.56	11.4
3rd "	30	0.82	17.60	1.47	12.0
4th "	43	0.45	17.51	1.51	11.6
5th "	74	0.27	17.19	1.30	13.2
Residue in bag		0.25	16.76	1.08	15.5

Fractions 2 and 3 were analyzed for individual amino acid and gave the values shown ( $R$  = ratio of nitrogen of each amino acid to  $\text{NH}_2$  nitrogen in the original substance, indicating the number of molecules of the amino acid).

	2nd diffusate		3rd diffusate	
	<i>per cent</i>	<i>R</i>	<i>per cent</i>	<i>R</i>
Glycine	49.7	6.0	46.8	5.9
Alanine	26.4	2.7	25.3	2.7
Serine*	21.2	1.8	22.4	2.0
Tyrosine	18.6	0.9	18.1	1.0

\* This value would include other hydroxyamino acids (threonine) (v. 10)

Although the substance III is certainly not homogeneous, it would appear that the fractions 2 and 3, which are similar in composition, consist largely of peptides with a chain length of twelve amino acids, and this receives support from the amino acid composition which, incidentally, is not far from the proportions found in silk fibroin<sup>7</sup> (Bergmann and coworkers, (11, 12)).

The results of inhibition tests with the fractions obtained by diffusion are given in Table III and show that there was no definite difference in the reactions of the five diffusates, the residue gave a somewhat stronger inhibition. On the whole the experiment renders it very improbable that a small quantity of a substance with high molecular weight was responsible for the specific inhibitions observed. Thus the analytical result showed that some separation with respect to molecular size had been obtained, as indicated by the figures for

<sup>7</sup> A non-crystalline substance, probably a tetrapeptide isolated by Fischer and Abderhalden (5) contained two glycine, one alanine, and one tyrosine residues.

the 1st and 5th diffusates, while this difference is not reflected in the inhibition effects

TABLE III

Inhibition tests with diffusates of substance III.

Tests as in Table I.

Diffusates	1	2	3	4	5	6	Control
<i>per cent</i>							
1/2	0 f tr	0 f tr	0 f tr	0 f tr	0 f tr	0 0	+ +
1/4	tr tr	tr tr	tr tr	tr tr	tr tr	f tr f tr	
1/8	± +	± +	± +	tr +	± +	tr +	

Continuation of the work in the direction of obtaining more homogeneous preparations of silk peptides is desirable as well as further investigations on other proteins

The author is indebted to Mr B Meier for his assistance

#### SUMMARY AND CONCLUSIONS

The foregoing experiments show that products of the hydrolysis of silk that consist of peptides having, from amino nitrogen determinations, molecular weights from about 600 to 1000 were capable of inhibiting the reactions of precipitin sera for silk. From the results it may reasonably be inferred that silk fibroin contains determinant structures not larger than the peptides examined, which probably consist of not more than 8 to 12 amino acids. That similar relations may obtain with other proteins is not improbable in view of results previously reported with dialyzable split products

#### BIBLIOGRAPHY

- 1 Landsteiner K. and van der Scheer, J *Proc Soc Exp Biol and Med*, 1931, 28, 983
- 2 Landsteiner K., and Chase M. W., *Proc Soc Exp Biol and Med*, 1933 30, 1413 see Holiday E *Proc Roy Soc. London Series A* 1939 170, 79
- 3 Bergmann, M. and Niemann, C *J Biol Chem* 1938 122, 577
- 4a Landsteiner K. The specificity of serological reactions, Chas. C Thomas, Springfield, 1936 17
- b Fell, N H *J Biol Chem* 1935, 109, p xxxi
- 5 Fischer E, and Abderhalden E, *Ber chem Ges* 1907 40, 3544
- 6 Abderhalden, E, and Bahn, A. *Z physiol Chem*, 1932 210, 246 1933, 219, 72 1940, 285, 23

- 7 Town, B W , *Biochem J* , 1936, 30, 1833
- 8 Bernhart, F W , *J Biol Chem* , 1938, 123, p x
- 9 Desnuelle, P , *Enzymologia*, 1938-39, 5, 37
- 10 Nicolet, B H , and Sidel, L J , *J Biol Chem* , 1941, 139, 477
- 11 Bergmann, M , and Niemann, C , *J Biol Chem* , 1938, 122, 577
- 12 Stein, W H , Moore, S , and Bergmann, M , *J Biol Chem* , 1941, 139, 481

## SYNTHESIS OF INOSITOL IN MICE

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Since it has been shown (1, 2) that inositol possesses vitamin activity, it has been desirable to investigate the metabolism of this compound. Some studies have been made previously, but the work has been seriously limited by the lack of suitable methods of quantitative estimation. With the development of a satisfactory micromethod for the estimation of inositol (3), it has been possible to study the metabolism of this substance in some detail. In particular, it has been possible to show that while mice require inositol in the diet, they are able to synthesize the compound when none is ingested. Furthermore, the site of synthesis has been indicated, and a possible explanation for the numerous spontaneous cures of alopecia (4) has been discovered. Finally, the influence of pantothenic acid on the metabolism of inositol has been demonstrated.

### EXPERIMENTAL

*Method of Analysis*—Inositol determinations were made according to the method recently described by Woolley (3). Individual mice were killed with chloroform, weighed and suspended in 50 cc. of HCl of such concentration that the final suspension was 18 per cent HCl. The mixture was refluxed for 6 hours and extracted twice with ether. The analysis for inositol was then conducted on the aqueous phase as previously described. In every case in which animals had received a diet containing inositol they were fed a ration free of this substance for 3 days before analysis. This was done in order to remove ingested inositol from the intestinal tract.

Variation in the values observed for individual male weanling mice is illustrated by the data given in Table I.

### *Synthesis of Inositol in Mice*

In order to determine whether mice were able to synthesize inositol, the following experiments were performed.

Forty five weanling male mice were fed a highly purified diet composed of sucrose, inorganic salts, casein, cod liver oil, corn oil, thiamin, riboflavin, vitamin B<sub>6</sub>, nicotinic acid, choline, and pantothenic acid. The composition of this diet has been described (2).

Ten mice were individually analyzed and the average inositol content of a weanling mouse was thus obtained (see Table II). After the animals had been

fed the purified ration for 2 weeks ten more animals were analyzed. A similar group was analyzed at 4 weeks and another group of five at 6 weeks. The inositol content of an average mouse at biweekly intervals on this diet is shown in Table II. It can be seen that the mice increased in total content of inositol per mouse even though none of this substance was ingested. For purposes of comparison the average inositol content of six mice raised on stock rations for 4 weeks after weaning is included in Table II. The inositol content of six

TABLE I  
*Inositol Content of Individual Weanling Male Mice*

Mouse No	Live weight	Inositol content
	gm	gamma/mg
240	7.5	0.50
241	8.5	0.50
242	8.5	0.47
240A	8.5	0.47
345	7.5	0.48
340	7.5	0.50
341	8.5	0.50
342	8.5	0.47

TABLE II  
*Inositol Content of Mice Fed Rations with and without Inositol*

Description of mice	Average live weight	Inositol content	Total amount of inositol
	gm	gamma/mg	mg
Weanlings	7.0	0.49	3.4
2 wks without inositol	15.0	0.35	5.3
4 wks without inositol	24.0	0.36	8.6
6 wks without inositol	35.0	0.35	12.3
4 wks on stock ration	25.0	0.39	9.8
4 wks with inositol	23.0	0.54	12.4

animals fed the highly purified ration plus 100 mg of inositol per 100 gm of ration for 4 weeks after weaning is also shown.

The experiment was repeated with a second group of nine mice. These animals increased in inositol content on the average from 4 mg to 12 mg in 6 weeks. The experiment was again repeated using eight animals. These increased in total inositol content from 4 mg to 11.4 mg.

In the presence of adequate pantothenic acid one characteristic of inositol deficiency was the variation in gain of weight which individual animals exhibited. Another characteristic was that, at about the 6th week of the experimental period, many showed a precipitous loss of weight. Unless inositol was fed when this loss of weight began, death resulted. The rate of loss was

as great as the rate of gain had been before the decline began. A mouse typical in this respect was No. 313, which gained from 9.5 gm. to 29.5 gm. in 5 weeks. In the following 10 days the weight declined to 21.5 gm. 100 mg. of inositol per 100 gm. of ration were added, and in the next 8 days the mouse increased in weight to 27.0 gm. When inositol was not administered to similar animals, death resulted after their weight had decreased to 15 to 20 gm. Death was averted only when inositol was fed soon after the loss of weight became apparent. In several cases these phenomena were not accompanied by alopecia at any stage of the experiment, and in no case was loss of hair observed during the period of precipitous loss of weight. Thus inositol deficiency was not invariably accompanied by alopecia.

The low incidence of alopecia has been reported on previous occasions (4). Examination of the data for individual mice in the first experiment described above demonstrated again that inositol deficiency cannot be produced in all animals. In contrast to the uniformity in content of inositol of weanling mice (Table I) it was found that several of the animals kept on the inositol free ration had a low content. Thus it was low in two out of the ten analyzed after 2 weeks (0.24 and 0.27 gamma per mg., as compared to 0.35 for the average of the group) and after 4 weeks in three out of ten (0.30, 0.29, 0.31 gamma per mg.). In an independent group of seven mice three showed precipitous loss of weight after 7 weeks; in a group of five mice two behaved similarly, while in a third group of seven two lost weight as described.

*Relation of Pantothenic Acid to the Synthesis of Inositol*—In order to investigate more fully the relationship of pantothenic acid and inositol to alopecia (4) the following experiments were performed. A group of twenty-two weanling mice were fed the above ration, minus pantothenic acid. Ten animals were analyzed at the beginning of the experiments. The remaining twelve were analyzed 3 weeks later. The average content of inositol in the first group was the same as that previously recorded in Table II for weanling mice (0.49 gamma per mg., 4.0 mg. per mouse). The average values in the second group were 0.24 gamma per mg. and 4.3 mg. per mouse. Thus the inositol content per unit weight decreased and the total amount of this substance in the mouse remained approximately the same.

The experiment was repeated twice with groups of six mice with the same result as in the first trial. In a fourth experiment with 12 mice the content of inositol did not decrease significantly (0.48 to 0.41 gamma per mg.) in 2 weeks, undoubtedly because of the small gain in weight of the group (from 6.5 gm. to 10 gm.). That is, the quantity of inositol contained in a mouse at the start and presumably carried through the test period was not distributed in as much tissue as in the other experiments.

Addition of pantothenic acid to the diet of animals deficient in this vitamin resulted in the synthesis of inositol. A typical experiment was as follows:



A group of fifteen mice were fed the ration deficient in pantothenic acid for 2 weeks. The average content of inositol at the beginning was 0.49 gamma per mg and the total amount in the average mouse was 4 mg. After the mice had been deficient in pantothenic acid for 2 weeks the content of inositol had decreased, but the total amount in a mouse was the same as at the beginning (judged from the average of two mice analyzed). Pantothenic acid was then restored to the diet. Two to 3 weeks after the restoration the typical alopecia of inositol deficiency made its appearance in seven of the mice. Four out of the seven hairless individuals exhibited spontaneous cure of the alopecia 2 to 3 weeks after its appearance even though no inositol was fed. Analyses of these spontaneously cured animals revealed that in them inositol had increased to normal values (0.39 gamma per mg, 11.7 mg per mouse). Analyses of those which remained hairless showed that they had not increased markedly in content of inositol.

### *Microbial Synthesis of Inositol*

In an effort to discover the reason for the spontaneous cures of alopecia which were observed (4, and above) the following experiments were performed.

The intestinal tract of a mouse which had exhibited spontaneous cure of alopecia was removed aseptically and placed in 10 cc. of a synthetic medium. This medium had the composition described by Woolley (5), except that inositol and thioglycolic acid were omitted. It was thus a highly purified mixture of all available growth factors and of glucose, inorganic salts, and amino acids. The tube was incubated for 24 hours at 37°, and then a drop of the suspension was introduced into a second 10 cc. of medium of the same composition. After 24 hours incubation, 1 cc. of this passage of culture of organisms from the intestinal tract was added to 500 cc. of medium of the same composition. Incubation at 37° was continued for 60 hours. The cells were then collected by centrifugation, hydrolyzed, and analyzed for inositol. The metabolism solution was concentrated under reduced pressure and similarly analyzed.

As is shown in Table III, the organisms obtained by passage of a culture from the intestinal tract synthesized inositol and at least 80 per cent of the amount formed was retained in the cells. The experiment was repeated with the same mixed culture (which had been stored at 0°) for an incubation period of only 16 hours. Approximately the same quantity of inositol was formed as previously. Hence the incubation periods in subsequent tests were 16 hours in length.

The intestinal tract of a mouse from the same group of animals which had lost its hair and had not exhibited spontaneous cure was treated similarly. The bacteria from this mouse showed a much smaller content of inositol (Table III). The experiments were repeated on two mice from a second run, one of which had become hairless but had then exhibited a spontaneous cure and the other of which had remained hairless. The culture of organisms from the first mouse synthesized 0.42 gamma of inositol per cc. of culture and that from the second mouse formed 0.12 gamma. A third experiment with two more mice, cured and hairless like the others, was performed in the same manner and it was found that the values were 0.40 and 0.0 gamma per cc. for the

culture from the spontaneously cured mouse and the hairless mouse respectively. In this case the hairless mouse was examined as soon as alopecia developed, while in the other instances animals were taken which had been hairless for about one week.

It has been found that the synthesis by the cells of the culture was not influenced by gramicidin and that a prominent intestinal inhabitant did not form inositol. One of the cultures already tested, which was procured from a mouse which had exhibited spontaneous cure of alopecia, was inoculated into a medium of the composition described above, to which had been added 10 gamma per cc of crystalline gramicidin<sup>1</sup>. A control test was done, using the same culture without the addition of gramicidin. The cells from each medium were collected and analyzed for inositol. As can be seen from Table III gramicidin did not

TABLE III

*Inositol Content of Cultures of Intestinal Organisms*

The numbers in parentheses indicate the length of the period of incubation

Material analyzed	Inositol content of culture
	<i>gamma/cc</i>
Cells of culture from spontaneously cured mouse (60 hrs.)	0.40
Supernatant fluid after centrifugation of the above cells	Less than 0.1
Cells of mixed culture from above mouse (16 hrs.)	0.38
Cells from the above culture grown in gramicidin	0.38
Cells of mixed culture from hairless mouse	0.18
Cells of <i>E. coli</i>	Less than 0.1

influence the synthesis. The cells of one of the most important bacterial forms in the intestinal tract of the mouse, *Escherichia coli*, as grown in the purified medium, were analyzed and found not to contain inositol in demonstrable amounts (Table III).

*Influence of Pantothenic Acid on Inositol Metabolism*

The occurrence of alopecia in a high percentage of the mice to which pantothenic acid had been restored after 2 or 3 weeks of deficiency has been mentioned above. It seemed likely that if inositol were fed from the beginning, this delayed appearance of alopecia might be prevented. A group of ten mice were fed the basal ration referred to throughout this paper, from which pantothenic acid was omitted and which was supplemented with 100 mg. of inositol per 100 gm. After 2 weeks pantothenic acid was restored and inositol was omitted. Two to 2½ weeks after this change typical alopecia developed in all but three of the animals. Analysis of three of the hairless mice showed that they contained little more inositol than did weanling mice (6.4 mg. compared to 4.5 mg.)

<sup>1</sup> We wish to thank Dr. R. J. Dubos for gifts of gramicidin.

Similarly, it had been found that two of the animals at the time that pantothenic acid was added were deficient in inositol even though they had received it in the diet (4.0 mg compared to 4.4 mg)

The experiment was repeated with the following modifications. A group of six mice were fed the ration which contained inositol but no pantothenic acid. After 2 weeks analysis of three mice again showed that they were deficient in inositol. The other three mice were continued on inositol for 3 days following the addition of pantothenic acid. Analyses of these revealed a normal content of the vitamin (0.42 gamma per mg). Thus it appeared that when pantothenic acid was absent from the ration inositol deficiency developed even though this substance was ingested. Addition of pantothenic acid to the diet restored the inositol content of the mice to normal within 3 days.

TABLE IV

*Distribution of Free and Total Inositol in Various Natural Products*

Except in the case of the extracts analyses were based on weights of undried samples

Material analyzed	Free inositol	Total inositol
	gamma/mg	gamma/mg
Normal mice (6 individuals)	0.25	0.41
Inositol-deficient mice (3 individuals)	0.20	0.30
Beef skeletal muscle	0.55	0.88
Beef brain	3.0	6.0
Beef pancreas extract	1.2	5.0
Aqueous alcohol extract of rice bran	0.37	0.53
Dialyzed rice bran extract	0.0	0.16

*Free and Combined Inositol*

Since it has been shown (6) that yeast is unable to respond to inositol esters, it was thought possible that the method for the estimation might be refined to differentiate free from combined inositol. It has been shown (2) that liver contains a non-dialyzable, water-soluble substance which liberates inositol when treated with acid or alkali. It has been found that yeast does not respond to this combination. This has made possible the analysis of natural products for free inositol, separate from total inositol. The difference between free and total represents combined inositol.

For the analysis of mice for free inositol the following procedure was used

A mouse was ground and suspended in water. An aliquot of this suspension was hydrolyzed with HCl and total inositol was determined in the hydrolysate as previously described. A second aliquot of the suspension was heated in an autoclave (15 pounds for 15 minutes), centrifuged, and the precipitate washed with water. Direct analysis of this liquid without acid hydrolysis gave a value for free inositol. Since the combined inositol present in liver extract, brain extract, pancreas extract, and rice

bran extract was not rendered available to yeast by autoclaving, this procedure was used to coagulate proteins and destroy enzymes.

By this technique approximately 60 per cent of the inositol content of normal mice was found to be free. Similarly, 50 per cent of the total inositol content of brain and 60 per cent of that in skeletal muscle was found to be free. The proportion of free inositol in normal mice did not differ significantly from that in deficient animals. Some representative data are shown in Table IV. In the case of tissues the value for free inositol represents the amount which can be extracted and does not include any free inositol which may be retained in insoluble residues.

#### DISCUSSION

It can be clearly seen from the data in Table II that mice synthesized inositol when fed the purified ration. It appears that the presence of pantothenic acid in the ration was of importance for this synthesis. Those animals which did not receive pantothenic acid failed to increase markedly in total inositol content even though they did gain in weight, whereas, when pantothenic acid was added to the ration, the inositol content of the mice increased. It may be of interest to note that in no case of deficiency did the total amount of inositol in a mouse decrease even though the content per unit weight did fall. Hence it was necessary that the animals should grow if the inositol deficiency was to be recognized by a decreased content of the vitamin per unit weight.

One site of inositol synthesis appears to be the intestinal tract. When a mouse exhibited spontaneous cure of alopecia, a simultaneous increase in the total content of inositol took place. Organisms cultivated from the intestinal tract of mice which had exhibited spontaneous cure synthesized inositol in the instances tested and to a much greater extent than did the organisms isolated by the same method of cultivation from hairless mice. Since the synthesis took place in the presence of gramicidin, which inhibits the growth of Gram positive bacteria (7) and since the gramicidin treated cultures on microscopic examination were found to be Gram negative, it is probable that the organisms responsible for the synthesis were Gram negative. However, a prominent Gram negative organism of the intestinal tract, *E. coli*, did not form inositol. Since inositol deficiency could be produced regularly in a small percentage of mice fed a deficient diet, it must be concluded that the inositol synthesized by such organisms was not sufficient to meet all of the requirements of the mouse, or else that, under the conditions studied, the organisms did not become established in all animals. This latter hypothesis may explain more adequately why only some animals on an inositol free diet develop alopecia. The data show further that the metabolism of inositol is influenced by pantothenic acid. Mice did not increase in total content of inositol even when this sub-

stance was present in the diet unless pantothenic acid was also present. It has not been established whether this phenomenon was due to failure of absorption or to some more obscure metabolic disturbance.

#### SUMMARY

It has been shown that mice are able to synthesize inositol. This synthesis was not observed when pantothenic acid was absent from the diet. Cultures from the intestinal tract of animals which exhibited spontaneous cure of alopecia yielded microorganisms which synthesized much more inositol than did organisms isolated in the same fashion from the tracts of mice that had become hairless. Some observations on the distribution of free and combined inositol have been made and it has been shown that several biological materials contain combined inositol. It has been found that deficiency of inositol can develop even when inositol is present in the diet if pantothenic acid is omitted.

#### BIBLIOGRAPHY

- 1 Woolley, D. W., *Science*, 1940, 92, 384
- 2 Woolley, D. W., *J. Biol. Chem.*, 1941, 139, 29
- 3 Woolley, D. W., *J. Biol. Chem.*, 1941, 140, 453
- 4 Woolley, D. W., *Proc. Soc. Exp. Biol. and Med.*, 1941, 46, 565
- 5 Woolley, D. W., *J. Exp. Med.*, 1941, 73, 487
- 6 Woolley, D. W., *J. Biol. Chem.*, 1941, 140, 461
- 7 Dubos, R. J., and Hotchkiss, R. D., *J. Exp. Med.*, 1941, 73, 629

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#### BIBLIOGRAPHY

- 1 Woolley, D. W., *Science*, 1940, 92, 384
- 2 Woolley, D. W., *J. Biol. Chem.*, 1941, 139, 29
- 3 Woolley, D. W., *J. Biol. Chem.*, 1941, 140, 453
- 4 Woolley, D. W., *Proc. Soc. Exp. Biol. and Med.*, 1941, 48, 565
- 5 Woolley, D. W., *J. Exp. Med.*, 1941, 73, 487
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Hemolytic "units" were measured as in (3) both in the original sera and in the supernatants.

In order to supply the missing components for the fortification of human complement in the hemolytic titration fresh supernatants from the above C' series were used, or, if these were not available, supernatants were quickly prepared as follows. For each milliliter of guinea pig serum specific precipitate was formed with about 0.02 mg of egg albumin nitrogen and 0.1 to 0.2 mg of rabbit anti-egg albumin nitrogen, or with similar amounts of Type II or Type III pneumococcus specific polyzac

TABLE I

*Human Complement Titrations with and without Reinforcement*

Human serum and dilution used	Guinea pig serum supernatant	Hemolysis by quantity of human serum dilution used:							
		0.03 ml.	0.075 ml.	0.1 ml.	0.15 ml.	0.2 ml.	0.25 ml.	0.3 ml.	0.4 ml.
B <sub>1</sub> 1 30	—						ac	c	
" " "	+			++++±	c				
C <sub>1</sub> 1 10	—					++++±	c		
1 30	+			+	+++	c			
E <sub>1</sub> 1 10	—	++		++++±	c	c			
" 1 40	+			+++	ac	c			
2 <sub>1</sub> 1 25	—					+	+++	++++±	
" " "	+	+++	ac	c					
13 <sub>1</sub> 1 10	—					+++		ac	
" 1 30	+	+++	ac	c					
17 <sub>1</sub> 1 10	—				ac	c	c		
" 1 30	+		ac	c	c				
28-32 <sub>1</sub> 1 40	—			0		ac			c
" 1 320	+			0		++			c

charide and homologous rabbit antibody. These quantities of specific precipitate have been shown to remove C'1, or the combining component(s), from complement. The mixture was centrifuged after the precipitate flocked and the supernatant was used as indicated.

### Experiments

For the typical titrations given in Table I 0.2 ml. of hemolytic system (equal volumes of 5 per cent sheep red cell suspension and a dilution of hemolysin containing 2 or 4 "units") was added to each tube, followed by 0.05 ml. of the guinea pig serum supernatant, made up to double the original serum volume. Varying volumes of diluted human serum were then added, followed by saline to a total of 0.5 or 0.6

ml. The usual controls were run, including one with 0.1 ml of guinea pig supernatant with saline and hemolytic system. This was negative in every instance. For each serum the first line in the protocol gives the titration without supplement, while the second line indicates the result of addition of the missing component or components.

*Lot D*—In an earlier experiment C' and iC' blanks with saline alone showed no less N than corresponding blanks with antigen and serum alone. Saline blanks were therefore dispensed with. As neutralization of guinea pig C' and iC' had been found unnecessary, this step was also omitted with the human sera and earlier protocols are not given. pH of C', 7.38, pH of iC', (after 50 minutes at 56°C), 8.21. Diluted anti-Pn III rabbit serum pool, B 40, 60 used. S III, 0.04 mg per ml. C'2 "titer" determined 1 week later after storage in CO<sub>2</sub> snow, 70 units per ml, C'1 "titer" (with guinea pig serum supernatant), 120 units. Tubes held at 19–21°C for 2.5 hours, overnight in ice box before centrifuging.

No of tubes	1	1	1	1	3	3	3	3	3	3
C ml	6 0	6 0						2 0	4 0	6 0
iC ml			6 0	5 5		2 0	6 0			
Serum dilution ml	1 0		1 0		1 0	1 0	1 0	1 0	1 0	1 0
S III dilution ml		1 0		1 0	1 0	1 0	1 0	1 0	1 0	1 0
Saline ml	1	1	1	1	6	4		4	3	1
N precipitated mg	0 012	0 012	0 018	0 024*	{ 0 444 0 448 0 446	{ 0 470 0 476 0 482	{ 0 492 0 500 0 492	{ 0 556 0 568 0 554	{ 0 624 0 590 0 610	{ 0 616 0 612 0 634
Mean	0 012		0 021		0 446	0 476	0 495	0 559	0 608	0 621
Subtraction of blank						0 007‡	0 021	0 004‡	0 008‡	0 012
Specific N precipitated mg						0 469	0 474	0 555	0 600	0 609
Subtraction of iC' value								0 469	0 472‡	0 474
C' N precipitated mg								0 09	0 13	0 14
C' N precipitated per ml C' taken								0 045	0 033	0 023

\* Calculated to 6.0 ml.

‡ Aliquot portion of blank on 6.0 ml.

§ Mean of the two iC' series values

Hemolytic units left in each 2, 4, 6 ml. C' supernatant respectively, <<40, <80, <<160

Data obtained with another portion (D') of the same lot kept frozen a week longer, and then analyzed, are given in Fig. 1

*Lot E*—Anti-Ea rabbit serum pool d, diluted to 3.5 volumes, (0.4 mg anti-Ea N per ml) and Ea, 0.04 mg N per ml were used as the immune system. C'2 "titer" of lot E, 70 units, C'1 "titer" (with guinea pig serum supernatant), 230 units. Tubes centrifuged after 3 hours at 20–21°C.

Portions of lot E, active and inactivated as in the previous section, were first treated with anti-Pn horse specific precipitate before addition of the rabbit system, as had been done in the study of guinea pig complement (3). The anti-Pn VIII horse serum H644 used had been precipitated with S III in another connection (7).



No. of tubes	1	1	1	1	3	3	3	3	3	3
C' ml	3.0	3.0					1.5	2.5	4.0	6.0
iC' ml.			3.0	3.0		3.0				
Serum dilution ml.	1.0		1.0		1.0	1.0	1.0	1.0	1.0	1.0
Ea dilution, ml.		0.5		0.5	1.0	1.0	1.0	1.0	1.0	1.0
Saline, ml.	1	0.5	1	0.5	3					1
N precipitated, mg	0	(Lost)	0.010	0	{ 0.394 0.386 0.396 }	{ 0.404 0.396 0.384 }	{ 0.460 0.464 0.464 }	{ 0.490 0.484 0.476 }	{ 0.506 0.512 0.500 }	{ 0.534 0.524 0.540 }
Mean	0		0.005		0.392	0.395	0.463	0.483	0.506	0.533
Subtraction of blank						0.005	0	0	0	0
Specific N precipitated, mg...						0.390	0.463	0.483	0.506	0.533
Subtraction of iC' value							0.390	0.390	0.390	0.390
C' N precipitated mg							0.07	0.09	0.12	0.14
C' N precipitated, per ml. C' taken							0.047	0.036	0.030	0.023

\* Since 3.0 ml. iC' gave the same value as the salt control series it is assumed that amounts of iC' corresponding to the other volumes of C' used would also have given the same value.

Hemolytic units left in each 1.5, 2.5, 4 6 ml. supernatant, respectively <7, <9 <12 20

and had been diluted to an anti S VIII content of 0.65 mg N per ml. After the reaction components were mixed, the tubes were allowed to stand 1 hour at 21°C

C' ml.	5	5	30	30	30
iC' ml.					
Saline ml.			0.5	0.5	30.5
Anti Pn VIII horse serum, ml	0.8		5.0	5.0	5.0
S VIII 0.17 mg. per ml., ml		0.2	1.0	1.0	1.0
N precipitated from aliquot, mg	0.016*	0.016*	{0.538 0.538 0.536}	{0.548 0.550 0.554}	{0.518 0.524 0.520}
Mean	0.016		0.537	0.551	0.521
Total N precipitated, mg			2.15	2.20	2.08
Subtraction of blank, mg			0.10	0.10†	
Specific N precipitated mg			2.05	2.10	2.08

\* Entire precipitate from blanks used for analysis.

† C' and iC' blanks in the preceding experiment with serum E were approximately the same. Mean blank (first 2 columns)  $\times 6$  used.

and were centrifuged in the cold. All supernatants were recentrifuged and the precipitates were washed 3 times with 10 ml. of chilled saline, dissolved in alkali, and rinsed into 20 ml. volumetric flasks. Aliquot portions of 5.0 ml. were analyzed for N.

The recentrifuged C', iC', and saline supernatants from the above reaction were set up with the same Ea and rabbit anti Ea dilutions used in the earlier experiment.

on untreated human serum E 6 ml. of each supernatant represented 4.9 ml. of the original C', iC', or saline

No of tubes	1	1	1	1	3	3	3	
C' supernatant, ml	6 0	6 0					6 0	
iC' " ml			6 0	6 0		6 0		
Saline " ml					6 0			
Anti Ea serum, ml	1 0		1 0		1 0	1 0	1 0	
Ea dilution, ml		1 0		1 0	1 0	1 0	1 0	
Saline, ml	1	1	1	1				
N precipitated, mg	0 024	0 008	Lost	0 014	{ 0 392 0 386 0 382	{ 0 410 0 406 0 396	{ 0 502 0 496 0 524	
Mean	0 016		0 014		0 387	0 404	0 507	
Subtraction of blank, mg							0 014	0 016
Specific N precipitated, mg							0 390	0 491
Subtraction of iC' value								0 390
C' N precipitated, mg								0 10

Hemolytic units taken, per 4.9 ml. original C', 1125  
 " " in C' horse serum blank, " " 930  
 " " " C'-S VIII " " 1030  
 " " " C'-S VIII-anti-Pn VIII supernatant, 960  
 " " " final supernatant, <16

Because of the apparent solubility effect in other experiments (see also Fig. 1) a run was made with 30 ml. of C' with the rabbit system. It was thought that at this volume the inhibiting effect of C' excess might be great enough to mask the addition of C' N and give N figures like those with S VIII and horse antiserum in spite of fixation of the C' present. A portion of lot H of human serum (C'1 "titer," 200 units per ml.) was used as no more of lot E was available. Anti-Pn-III rabbit serum B 40, diluted to 9 volumes. S III, 0.19 mg per ml. Tubes allowed to stand at room temperature for 3 hours, in ice box overnight. Analyses run as in protocol 2, lot E.

C', ml	10	30.0	
Saline, ml	2		30
Anti-Pn III rabbit serum, ml		5.0	5.0
S III solution, ml		1.0	1.0
N precipitated from aliquot, mg	0.032	$\begin{cases} 0.750 \\ 0.756 \\ 0.754 \end{cases}$	$\begin{cases} 0.570 \\ 0.574 \\ 0.566 \end{cases}$
Mean	0.032	0.753	0.570
Total N precipitated, mg		3.01	2.28
Subtraction of blank, mg		0.10	
Specific N precipitated, mg		2.91	2.28

The difference between the C' and saline series, 0.63 mg of N indicates that the apparent solubility effect does not account for the values found with S VIII and anti Pn VIII horse serum

*Lot G'*—A comparison was made of the C' N removed from this serum by two different immune systems, Ea anti Ea, and S II-anti Pn II. The former was that used in the preceding instance. Ea solution 0.045 mg N per ml. Anti Pn II rabbit serum 580, diluted to 4 volumes with saline. S II, 0.1 mg per ml. C'2 'titer' of lot G', 80 units. C'1 'titer' (with guinea pig serum supernatant), 800 units

No. of tubes.	1	1	1	3	3	3	2
C', ml.	1.0	2.0	2.0			2.0	2.0
Anti Ea dilution, ml				1.0			1.0
Ea dilution, ml	0.2			1.0			1.0
Anti-Pn II dilution ml		0.5			1.0	1.0	
S II dilution, ml			0.5		1.0	1.0	
Saline, ml	0.2	0.5	0.5	2	2		
N precipitated, mg	0.006	0.006	0.002	$\left\{ \begin{array}{l} 0.448 \\ 0.438 \\ \text{Lost} \end{array} \right.$	$\left\{ \begin{array}{l} 0.120 \\ 0.146 \\ 0.150 \end{array} \right.$	$\left\{ \begin{array}{l} 0.198 \\ 0.198 \\ 0.210 \end{array} \right.$	$\left\{ \begin{array}{l} 0.528 \\ 0.526 \end{array} \right.$
Mean	0.012*	0.004		0.443	0.139	0.202	0.527
Subtraction of blank						0.004	0.012
Specific N precipitated, mg						0.198	0.515
Subtraction of saline blank value						0.139	0.443
C' N precipitated, mg						0.06	0.07

\* Calculated to 2.0 ml.

Hemolytic units left in each Ea system supernatant, <13 in Pn II system supernatant, 20

*Lot 19<sub>2</sub>*—C2 'titer' <75 units. C'1 'titer', 400 units per ml. This human serum, containing antibodies to Type II pneumococcus, was preserved with 1:10,000 merthiolate and handled and analyzed so as to favor sterility. Estimation of C' N on 2.5 ml. samples with Ea-anti Ea as in previous examples gave 0.08 mg. C' removal was practically complete. 4.5 ml. portions of the supernatants from the C' analysis corresponding to 2.5 ml. of original serum, were each mixed with a solution of 0.06 mg. of S II and allowed to stand in the ice box for 5 days since in this and other instances of the analysis of weak human sera precipitation increased visibly during the first few days. Similar analyses were made with fresh serum 19<sub>2</sub> containing C. Blanks were also run and deducted.

Specific N from 2.5 ml. containing C', 0.117 mg

Anti-S II N from equivalent volume 'decomplemented' serum 0.090 mg

Human C' N removed by S II-human anti S II, 0.027 mg

C'1 units in supernatant calculated to original volume 160 per ml.

In this instance the human specific precipitate took up 30 per cent of its weight of C' and removed more than one-half of the number of C'1 units present

## DISCUSSION

It was shown in the introduction and in Table I that titration of human complement in the usual way does not yield the same information as with guinea pig complement and a new titration procedure for overcoming this difficulty was proposed. It is evident from the Experimental part, however, that one need not remain content with relative figures, and that the quantitative estimation of complement combining component or components in absolute terms, or weight units (3) is applicable without modification to human sera.

The amounts of complement nitrogen added to specific precipitates in fresh human serum are of the same order of magnitude as in guinea pig serum, but there seems to be little relation to the hemolytic titers of the various samples, whether these titers were obtained in the usual way or with added guinea pig serum supernatant. The reason for this is not clear but may be related to the growing mass of evidence that other components of  $C'$  as well as  $C'1$  are taken up.

When the present method for complement estimation (3) was proposed, it was made clear that the nitrogen determined was that of complement as defined by Muir (8) and that the designation  $C'1$  N was a provisional one in accord with current belief that the combining component, or components, consisted mainly of "midpiece" or  $C'1$  (9, 10). The inadequacy of this belief has often been maintained (11). It has now been shown in new work by Ecker and Pillemer (12) and by our own studies, which it is hoped soon to publish, that other complement components also add to specific precipitates. The quantitative method therefore remains, as before, a valid one for the estimation of complement or, more strictly, complement combining components in weight units.

Fig. 1 shows that the apparent solubility effect is also present as in guinea pig complement. If the lines in the figure are extrapolated roughly to zero volume they lead to the conclusion that the sera analyzed contain between 0.03 and 0.05 mg. per ml. of nitrogen due to complement combining component or components. This might provisionally be taken as the normal range of fluctuation for human sera. Many other samples, both from normals and from cardiac and hypertensive cases, have fallen within the same limits. These are not shown in the chart, partly to avoid overcrowding, and partly because many of the analyses were carried out with a single volume of serum.

It is also shown in the experiment on lot G' that the quantity of  $C'$  N found does not depend on the immune system used and is like that found in other sera with S III-anti-S III.<sup>3</sup> The second portion of the experiment on lot E, however, shows that human complement does not add to a specific precipitate from anti-

<sup>3</sup> Irregular results with the S I-anti-Pn I rabbit serum system in guinea pig and human sera are under investigation.

pneumococcus horse serum, and that in this respect, also, it resembles guinea pig complement (3, 13). The experiment shows, further, that the nitrogen ascribed to C' cannot be due to insoluble or easily adsorbed material other than C', since no more nitrogen was carried down by quite adequate amounts of the horse specific precipitate from C' than from 1C' or saline. Moreover the supernatant showed very nearly the same quantity of C'1 N, when subsequently treated with egg albumin rabbit anti-egg albumin as did the untreated portion of lot E.

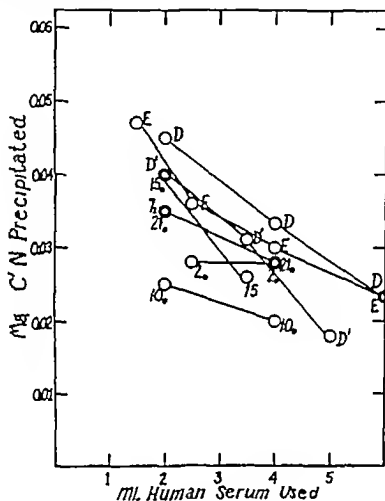


FIG 1

Initial experiments, as with lot 19<sub>1</sub>, indicate that human complement may be fixed in amounts comparable to those of guinea pig complement by human antipneumococcus serum in the reaction with homologous polysaccharide. This is perhaps surprising in view of Horsfall and Goodner's observation (14) that guinea pig complement is not fixed by human sera in reacting with encapsulated pneumococci.<sup>4</sup> The fixation of appreciable amounts of

<sup>4</sup> Fixation of human complement by human immune sera is evidently subject to unknown factors. Thus far 4 sera have shown precipitation of more specific N in the presence of human C' than in its absence but in only 2 of these was the decrease in "titer" checked. Two other sera, on the other hand showed no difference in specific N and no decrease in "titer."

human C' N in the S-human-anti-Pn system complicates the interpretation of these and other precipitin reactions in human sera. It is quite likely that small quantities of antibody, such as might occur during convalescence or after active immunization, could easily appear to be doubled (*cf* 4) by the C' N fixed during combination of the antibody with antigen and thus indicate too high an antibody content. It is also possible that inactivation of human sera for a period long enough to abolish fixation of C' N (50 minutes at 56°C) would damage small amounts of antibody. Therefore it appears best, while these possibilities are being investigated on a large number of sera, to remove C' by the method used in the experiments referred to, namely, by absorption with adequate amounts of an unrelated precipitating system, such as Ea-rabbit anti-Ea. Attention is also called to the length of time (4 to 5 days at 0°C) required for complete separation of small quantities of specific precipitate from human sera, a period which seems to be lengthened, rather than diminished, by the coprecipitation of active complement. As is stated in (3) flocculation even of relatively large amounts of specific precipitate from rabbit antibody is delayed by guinea pig C'. The same observation was made throughout the experiments with human C' and in many instances the delay in flocculation was even more marked than with guinea pig C'.

#### SUMMARY

1 A modified method is given for the titration of human complement so that C'1 titers are measured, as in guinea pig serum, instead of the C'2 titers yielded by the usual titration.

2 The measurement of complement combining component or components in weight units, instead of relative terms, is carried out as in guinea pig serum and leads to similar values, 0.03 to 0.05 mg. of C' N per ml. of human serum.

3 Other similarities in human and guinea pig complements are noted and discussed.

#### BIBLIOGRAPHY

- 1 Hegedüs, A., and Greiner, H., *Z. Immunitätsforsch.*, 1938, 92, 1.
- 2 Pillemer, L., Ecker, E. E., Oncley, J. L., and Cohn, E. J., *J. Exp. Med.*, 1941, 74, 297.
- 3 Heidelberger, M., *J. Exp. Med.*, 1941, 73, 681.
- 4 Heidelberger, M., Weil, A. J., and Treffers, H. P., *J. Exp. Med.*, 1941, 73, 695.
- 5 Heidelberger, M., Rocha e Silva, M., and Mayer, M., *J. Exp. Med.*, 1941, 74, 359.
- 6 Heidelberger, M., Kendall, F. E., and Soo Hoo, C. M., *J. Exp. Med.*, 1933, 58, 137. Heidelberger, M., and Kendall, F. E., *J. Exp. Med.*, 1935, 61, 595, 62, 697.
- 7 Heidelberger, M., Kabat, E. A., and Mayer, M., *J. Exp. Med.*, 1942, 75, 35.
- 8 Muir, R., *Studies in immunity*, London, Oxford University Press, 1909.

- 9 Osborn, T W B , *Complement or alexin*, London, Oxford University Press, 1937
- 10 Zinsser, H , Enders, J F , and Fothergill, L D *Immunity Principles and applications in medicine and public health*, New York, The Macmillan Co , 5th edition, 1939
- 11 For example, Bier, O G , *Z Immunitätsforsch* 1936, 89, 218
- 12 Ecker, E E., and Pillemer, L , in press.
- 13 Zinsser H., and Parker, J T , *J Immunol* 1923, 8, 151
- 14 Horsfall, F L , Jr , and Goodner, K., *J Immunol* , 1936 31, 135





# THE EFFECT OF UNDERNOURISHMENT ON THE SUSCEPTIBILITY OF THE RABBIT TO INFECTION WITH VACCINIA\*

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It is generally believed that the healthy, well nourished person is more resistant to disease than the individual who is already diseased or poorly nourished. That such is not the case, however, has long been recognized in certain instances of viral infection. Jenner (1) found that individuals with another disease were sometimes immune to vaccination. Underwood (2) in 1799 pointed out that poliomyelitis attacked the finest children. Rous (3) in 1911 reported that healthy fowls are more susceptible to infection with sarcoma virus than unhealthy ones. Rivers (4) reviewing these and similar observations with viruses, has suggested that such behavior is not wholly unexpected and may be related to the extreme type of parasitism exhibited by viruses, namely, the dependence of viral disease on the multiplication of virus in susceptible cells.

At the present little is known concerning the factors upon which susceptibility of a cell to virus infection depends. However, it is reasonable to suppose that a poorly nourished cell may be lacking in some of the materials necessary for the formation of new virus particles. With this possibility in mind, it was decided to study quantitatively the effect of undernourishment on the susceptibility of the skin to infection with vaccinia. In spite of the fact that the rabbit is an extremely unsatisfactory animal for metabolic experiments, it was chosen for this work because it is well suited for precise quantitative studies with vaccinia.

The first experiments reported here confirmed fully the previously cited observations, in that they showed that simple undernourishment decreases the susceptibility of the rabbit's skin to infection with vaccinia. However, it became apparent from other experiments that simple reduction of available nutrient materials is not the sole factor involved in this decreased susceptibility. One other factor shown by the present experiments to be important is the amount of interstitial fluid present. In the presence of an increase of this

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fluid the virus particles tend to remain localized at the site of injection, this localization, as shown in an earlier paper (5), suggests that the virus comes into contact with fewer susceptible cells and the number of lesions is thereby reduced. The opposite is true where the amount of interstitial fluid is either normal or reduced.

The amount of interstitial fluid increases if animals are deprived of food but are permitted to drink water freely. This increase is not the result of lowered plasma proteins, as these are unchanged. It is prevented, however, if no water is administered by mouth or if physiological saline solution is administered parenterally. It is therefore apparent that experimental techniques are at hand for studying the effects both of undernourishment and of variations in the amount of interstitial fluids. This paper is a report of the influence of these factors on vaccinia infection.

### *Methods and Materials*

*Animals*—Normal white adult male rabbits weighing between 2 and 3 kilos were used.

*Virus*—The virus employed in the first 3 experiments was provided by Dr. J. W. Beard. This strain was derived from vaccine lymph originally obtained from the North Carolina Laboratory of Hygiene, Raleigh, and has been described in detail (6). This virus had been passed 50 times in rabbit skin. It was purified as described by Craigie and Wishart (7) and Parker and Rivers (8). Measured amounts were rapidly lyophilized and sealed in a vacuum until used in these experiments.

The virus used in the other experiments was a strain of vaccinia supplied by Dr. T. M. Rivers. This strain had been derived through serial passage through rabbit skin for a number of years and was well adapted to this animal. This strain was purified as was the other strain. It was not lyophilized but was kept frozen in dry ice until used.

*Conditions of Fasting*—The rabbits to be fasted were kept in cages with wire mesh bottoms sufficiently large to prevent the eating of feces. Three different regimes of fasting were observed in these experiments. In the first, the rabbits received no food but were given free access to water. In the second, neither food nor water was given. For the third, the animals were fasted with access to water and in addition were injected intraperitoneally with 50 cc. of physiological saline solution twice daily. These regimes were maintained for 10 days before virus inoculation and for 48 hours afterward. The animals were then allowed such small amounts of food that their weights remained stationary. The rabbits of the group deprived of both food and water were given free access to water as well as some food 48 hours after vaccination. Estimations were made of plasma proteins in most of the fasted animals. No significant changes were noted, so that this factor could be ruled out as an influence in the production of hydration.

Seven days after virus inoculation all the rabbits were killed and necropsied. The animals listed in Table I as fasted were practically free of any subcutaneous, mesenteric, perirenal, or any other deposits of fat. Six of the 21 rabbits which were

fasted with water were found to have some fat and have been listed as incompletely fasted.

*Controls*—The control animals were kept on the usual stock diet. Normal deposits of fat were seen in all of them. Certain of the fasted rabbits which failed to lose fat served as additional controls. A few of the rabbits developed diarrhea during the course of the experiment, some before and some after vaccination. These were excluded from the experiments since this complication had been seen to affect susceptibility to viral infection. The incidence of this complication was as follows: 3 of 21 control rabbits, 3 of 21 rabbits which were fasted but given water, 3 of 9 rabbits which were fasted and given isotonic saline solution, and none of the 9 rabbits which were given neither food nor water. Two of this last group, however, died of inanition.

*Virus Inoculation*—Tests for susceptibility to infection were made by intradermal injection of 0.25 cc. of 7 fourfold dilutions of virus. Each rabbit received 7 inoculations of each dilution or a total of 49 inoculations in each animal. The 50 per cent points were calculated by the accumulation positive and negative method of Muench and Reed (9).

*Spread of Materials*—This was studied by the intradermal injection of 0.5 cc. of an India ink suspension. The spread of India ink was measured with a planimeter immediately after injection and at 1, 2, and 4 hours afterward. Only the 4 hour readings are given. The technique of this procedure is given in detail elsewhere (10).

Throughout this paper the expression, fasted animals, will mean those which were deprived of food but given free access to water.

#### EXPERIMENTAL

*The Effect of Undernourishment*—An experiment was done on the effect of the deprivation of food but not water on the susceptibility of the rabbit to viral infection. Food was withheld from rabbits, but they were given access to water, and 3 were kept as controls. The results of inoculation of graded quantities of virus in this group are given under Experiment 1 in Table I. In the 3rd column are the number of inoculations of each dilution injected and in the 4th the per cent change in weight occurring during fasting prior to inoculation. Here it is seen that while the controls lost only 1 per cent of their weight the loss in the fasted animal was 19 per cent. In the 5th column are given the 50 per cent points. The logarithm of the virus dilution corresponding to the 50 per cent point for the control animals is 6.85 (dilution 1:7,080,000). In contrast, that for the fasted animals was 5.88 (1:759,000). The difference in logarithms was 0.97, the antilogarithm of which is 9.3. Therefore, the fasted animals may be thought of as being more than 9 times as resistant to viral infection as the controls. This result is well within the limits of the method of infectivity measurement and therefore indicates a definite increase in resistance related to fasting.

Viewed solely in the light of response as measured by the respective 50 per cent points the data obtained in this experiment might well be construed as

indicative of increased resistance due solely to poor nutrition. That this was not necessarily the case, however, was evident in associated findings. For one thing, it was observed that the blebs raised by the injections of the virus preparations subsided much more slowly in the fasted animals than did those in the controls. In earlier work (11) it was found that when blebs subside slowly the spread of particulate matter is correspondingly less than in instances where the blebs disappear rapidly. This was of particular interest in the present problem for it has been observed (5) that localization of injected virus due to failure to spread is associated with diminished likelihood of infection. A study was then made to learn whether or not the spread of India ink is altered in animals fasted as in the present experiment.

*Comparison of Susceptibility and India Ink Spread in Undernourished Rabbits*—An experiment was carried out to find whether deprivation of food but not water actually localized the virus as the foregoing observations suggested. This question is important for it has been shown (5) that localization of a virus diminishes the chance of infection. Therefore, in the present experiment both virus and India ink were injected into the skin of 3 fasted animals and 2 controls. As might have been expected from Experiment 1, the results (Table I, Experiment 2), indicate that the spread of India ink was considerably less in the fasted animals than that in the controls. In the latter the mean area of spread was  $7.84 \text{ cm}^2$  as compared with  $5.68 \text{ cm}^2$  in the fasted animals. In the same group, the logarithm of the respective dilution of virus was 6.86 (dilution 1:7,244,000) for the controls and 5.64 (1:437,000) for the fasted animals. It thus appears that the decreased spread in the fasted rabbits parallels the increase in resistance.

*Effect of Undernourishment with and without Increase in Interstitial Fluid*—Since the chance of viral lesions is decreased by localizing the virus (5), it was thought likely that some, at least, of the above results might be due to a reduction in spread of virus rather than to a change of the susceptibility in the individual cell directly referable to undernourishment. To determine this point a method was needed by which rabbits might be brought to a poorly nourished condition without any change in the spread of materials in the skin. Taylor and Sprunt (12) have shown that the spread is reduced by an increase in interstitial water and aided by the opposite. It was therefore possible that the failure of particulate matter to spread, as noted in the last experiment, was due to an increase in interstitial fluid. If present, such an increase would have to be dependent on some factor other than decreased plasma proteins, for these were normal. Regardless of the mechanism responsible for the accumulation of interstitial fluid, edema does not develop if the animal is deprived of water. The observation was also made that increases in interstitial fluid can be prevented if the fasting animal is injected intraperitoneally with physiological saline solution. It is beyond the scope of this paper to attempt

TABLE I

*The Effect of Undernourishment on Susceptibility to Infection with Vaccinia (As Indicated by the 50 Per Cent Point)*

	No. of rabbits used	No. of injections of each dilution	Change in weight before vaccination per cent	Log of 50 per cent point	Mean spread of India ink in 4 hrs. sq cm	Increased resistance over controls X
Experiment 1						
Controls	3	21	-1.1	6.85	—	—
Fasted with water	3	21	-19.1	5.88	—	9
Experiment 2						
Controls	2	14	+4.4	6.86	7.84	—
Fasted with water	3	21	-11.7	5.64	5.68	11
Experiment 3						
Controls	3	21	-0.6	6.23	8.91	—
Fasted with water	2	14	-27.4	5.35	5.38	7
Fasted with saline injected	1	7	-18.6	6.07	—	1
Experiment 4						
Controls	2	14	-1.8	8.86	8.63	—
Incompletely fasted with water	2	14	-17.2	8.44	7.51	3
Fasted with saline injected	2	14	-24.4	8.86	8.71	0
Experiment 5						
Controls	3	21	-2.8	8.07	7.38	—
Fasted with water	1	7	-18.5	6.67	5.38	12
Fasted without water	3	21	-22.6	7.98	—	0
Incompletely fasted with water	1	7	-20.0	8.14	7.40	0
Experiment 6						
Controls	3	21	-1.7	7.70	8.07	—
Fasted with water	1	7	-18.2	7.07	5.74	4
Fasted without water	2	14	-23.1	7.69	—	0
Incompletely fasted with water	2	14	-20.3	7.56	—	1
Experiment 7						
Controls	2	14	-2.5	7.85	7.27	—
Fasted with water	1	7	-16.0	7.06	7.93	6
Fasted without water	2	14	-29.4	7.75	—	0
Incompletely fasted with water	1	7	-17.6	7.71	7.41	0
Fasted with saline injected	3	21	-21.5	7.45	—	2

to explain these peculiarities in the metabolism of the rabbit. A series of experiments (Nos 3 to 7) was undertaken in which, by utilization of these two facts, it was possible to determine the effects of increased interstitial fluids and of simple undernourishment and to relate the former with the spread of India ink

The results of these experiments are shown in Table I. This table shows conclusively that the fasted animals with increased interstitial fluid required from 3 to 12 times more virus to infect than did the controls. Moreover the spread of India ink was also reduced. This reduction of spread was certainly associated with, if not caused by, accumulation of excessive water in the tissues, for it was observed that the animals in this group (with the exception of those in Experiment 3) always lost less weight than the ones which were deprived of water or given physiological saline solution intraperitoneally. This difference is apparently due to the fact that, if allowed to drink water, the fasted rabbits store it in the interstitial spaces.

If the animals were deprived of both food and water (dehydrated), essentially the same amount of virus was needed to infect as in the controls. The same was true in the case of those animals which received intraperitoneal injections of isotonic saline solution. Unfortunately, in all but one instance, in which the spread was slightly larger than in the controls, measurements of the India ink spread in these 2 groups were unsatisfactory, and correlation of susceptibility with spread of particulate matter is therefore impossible. However, in both groups, the blebs raised by the injection of the India ink suspension disappeared very rapidly, most of the ink remaining near the point of injection. The identical behavior of the blebs in these 2 groups indicates that dehydration of the interstitial tissues characterizes both groups. Apparently, the tissues were so dry that they allowed the menstruum of the ink to pass easily through the skin, while the large ink particles remained where they were injected. Experiments are now under way to determine the amount of interstitial water by direct measurement.

In addition to the above changes it was also noted that the animals deprived of both food and water and those that received physiological saline solution (dehydrated) had lesions which were relatively much smaller and which appeared about 24 hours later. Their lesions regressed somewhat sooner than did those in the controls. The lesions in the rabbits which received no food but were given water (increased interstitial fluid) were also smaller than in the controls but this difference was not as marked as with the above groups.

In other words, depriving rabbits of food increases the resistance of the rabbit to infection with vaccinia, this resistance is accentuated by increase of interstitial fluids, and is offset by dehydration of the interstitial spaces.

#### DISCUSSION

These experiments show that the response of rabbits to viral infection is affected in two ways by undernourishment. One is the depletion of the necessary intracellular elements for virus multiplication. As pointed out earlier in this paper, a susceptible cell must contain, regardless of its other requirements, the necessary constituents for virus multiplication. At present little is

known as to what these requirements are, but Hoagland and associates (13) have shown that biotin is always present in purified vaccinia and is probably a necessary constituent of the virus. Other substances of which the body has been depleted by undernourishment are probably equally necessary for virus multiplication. According to this concept increased resistance to viral infection depends in some part at least on the absence of materials required for synthesis of the virus.

The other influence is more striking and is associated with a change in the amount of interstitial fluids. It has been shown previously in this laboratory (5, 12) that alteration in the amount of these fluids modifies the extent of spread of particulate matter in the tissues and that this spread can be correlated with the capacity of a virus to produce lesions. Increase in interstitial fluids decreases the spread of particulate matter and reduces the incidence of viral lesions, while decrease in these fluids has the opposite effects. It is quite likely that this relationship can be explained simply on the basis of number of cells exposed to the action of the virus, for as shown in this laboratory (5) and by Olitsky and Schlesinger (14), the larger the area of dissemination of a virus the greater the likelihood of its coming into contact with a susceptible cell and hence the greater the chance of a lesion. The experiments reported here are entirely compatible with such an hypothesis. However, an alternative possibility is that the susceptibility of the individual cell may be modified by changes in the amount of interstitial fluid. The whole question of the mechanism of water balance on susceptibility to infection is being studied further.

It seems likely from the present experiments that both mechanisms are involved in determining the incidence of lesions. Deprivation of food resulted in either fewer or smaller lesions. This effect was accentuated in the presence of accumulation of interstitial fluids but was partially nullified if the interstitial tissues were dehydrated.

In this laboratory it has been observed that, generally speaking, rabbits do not react as well to infection with vaccinia in summer as in winter. This may be the result of increased fluid in the tissues consequent upon changes in food and water intake in hot weather. If this is so then experimental work with vaccinia and perhaps some other viruses might be facilitated in the summer by the injection of suitable amounts of isotonic salt solution.

The possibility that invasion of the central nervous system by the virus of poliomyelitis may be aided by dehydration is also suggested. De Rudder and Petersen (15) noted that poliomyelitis occurred among athletes in a boys' school after strenuous exercise and thought that the virus was already present and gained access to the nervous system because the nerve cells had been rendered more susceptible. Perhaps the dehydration associated with the exercise may have increased the spread of the virus in the nervous tissue and thus led to infection.

## SUMMARY

Experiments are reported in which it is shown that if rabbits are deprived of food, the lesions resulting from injection of vaccinia are either fewer or smaller, presumably this is partially explainable on reduction of available nutrients in the cell. The number and character of the lesions are also modified by the state of hydration of the interstitial tissues. If the amount of interstitial fluid is increased by permitting the animal to drink water, the lesions are even less numerous, but if the interstitial tissues are dehydrated either by withholding water or by injecting physiological saline solution into the peritoneal cavity, then the lesions are more numerous.

The increase in interstitial fluids in these experiments was not due to decreased plasma proteins, for these were normal. In this respect, therefore, the rabbit differs from man, for unless the plasma proteins are reduced, simple starvation in man results in dehydration rather than edema of the tissues.

From these experiments it is concluded that the virus is less able to multiply in the poorly nourished cell than in the well nourished one, and that hydration of the tissues increases the resistance of the tissue to infection while dehydration has the opposite effect. It is suggested that this is because hydration tends to localize the virus *in situ*, with result that fewer cells are exposed to it, while dehydration has the opposite effect. However, actual changes in cell susceptibility consequent upon altered water balance may be responsible for the effect.

## BIBLIOGRAPHY

- 1 Jenner, E, *Med and Physiol J*, 1804, 12, 97
- 2 Underwood, M, A treatise on the diseases of children, with general directions for the management of infants from the birth, London, J Mathews, new edition, 1789
- 3 Rous, P, *J Exp Med*, 1911, 13, 397
- 4 Rivers, T M, in Infantile paralysis, New York, The National Foundation for Infantile Paralysis, Inc., 1941, 58
- 5 Sprunt, D H, *J Exp Med*, 1941, 74, 81
- 6 Beard, J W, Finkelstein, H, and Wyckoff, R. W G, *J Immunol*, 1938, 35, 415
- 7 Craigie, J, and Wishart, F O, *Brit J Exp Path*, 1934, 15, 390
- 8 Parker, R. F, and Rivers, T M., *J Exp Med* 1935, 62, 65
- 9 Muench, H, and Reed, L J, *Am J Hyg*, 1938, 27, 493
- 10 Sprunt, D H, and McDearman, S, *Endocrinology*, 1939, 25, 308
- 11 Sprunt, D H., McDearman, S, and Raper, J, *J Exp Med*, 1938, 67, 159
- 12 Taylor, H, and Sprunt, D H., in preparation
- 13 Hoagland, C L, Ward, S M, Smadel, J E, and Rivers, T M, *Proc Soc Exp Biol and Med*, 1940, 45, 669
- 14 Olitsky, P K, and Schlesinger, R. W, *Science*, 1941, 93, 574.
- 15 De Rudder, B, and Petersen, G A, *Klin Woch*, 1938, 17, 699



## THE REACTION OF PERIPHERAL BLOOD VESSELS TO ANGIOTONIN, RENIN, AND OTHER PRESSOR AGENTS\*

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PLATES 7 AND 8

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One of the characteristics of the pressor substance which may cause essential hypertension in man or experimental renal hypertension in dogs must be an ability to elevate arterial pressure by constricting the arterioles sufficiently to increase peripheral resistance but not sufficiently to reduce blood flow. Clinical experience indicates that patients or animals with hypertension do not have cold, pale skin indicative of reduced blood supply. On the contrary, the plethoric appearance of many such patients is well known.

Experiments, both on animals and man, show that the ability of pressor substances to cause vasoconstriction varies greatly, not only in the same, but in different segments of the vascular system. For example pitressin and adrenalin have in common the ability to reduce blood flow severely while the former elevates arterial pressure but little and the latter strongly. As Landis, Montgomery, and Sparkman (1) pointed out, pressor agents which severely reduce blood flow to the periphery in relation to their ability to raise blood pressure, could scarcely be expected to be concerned in the genesis of hypertension characterized by normal or even elevated peripheral blood flow. They found in rabbits that renin was unusual among the other pressor substances in elevating arterial pressure without consistent reduction of skin temperature, —which was accepted as a rough measure of peripheral blood flow.

The demonstration that renin itself was not a pressor substance but produced elevation of pressure only after interaction with renin-activator and the liberation of angiotonin (2, 3) required that it also be shown that purified angiotonin elevates arterial pressure without significant fall in peripheral blood flow.

Corcoran and Page (4) found no consistent change in skin temperature of trained normal dogs when angiotonin was infused. Both renin and angiotonin

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Except for such small changes in diameter, the venules did not react visibly to renin

*Capillaries*—Although the walls could be seen very clearly, no active constriction was observed when renin was injected, the lumens remaining open at all times. Renin did not cause any increase in sticking of leukocytes to the walls, such as described by Clark and Clark (11). It did not produce any concentration of corpuscles, such as occurs following marked increase in capillary permeability, with loss of fluid into the surrounding tissue. Nor did it cause diapedesis, hemorrhage, or visible endothelial injury.

### *Reaction of the Vessels to Angiotonin*

Forty injections of angiotonin were made, and three different preparations used.

*Arterioles*—Angiotonin always caused arteriolar constriction. As with renin, such constriction began in different arterioles at slightly different times, but in all started between 0.7 and 1.0 minute after the beginning of the injections. Maximal constriction was reached within 1.0 to 1.5 minutes following the injections, and the arterioles returned to their original diameters within 2.0 to 11.0 minutes.

The following example illustrates the typical response of an arteriole 28 microns in diameter to 0.2 cc of angiotonin. Constriction began 1.0 minute after the start of the injection, and became maximal 1.4 minutes following the injection. Three minutes after the injection the arteriole had returned to its control diameter. Fig. 14 shows arteriolar constriction produced by 0.2 cc of angiotonin.

Increasing the amount of angiotonin injected caused greater arteriolar constriction. The increase in constriction, however, was not proportional to the increased amounts of angiotonin injected. Thus 0.25 cc of angiotonin caused an arteriole 31 microns in diameter to constrict to 0.88, 0.5 cc to 0.77, and 1.0 cc to 0.67 its original diameter. The effect of increasing the amount of angiotonin from 1.0 to 2.0 cc is shown by another experiment. One cc of angiotonin caused an arteriole 30 microns in diameter to constrict to 0.5 its original size (*cf* Fig. 9), and 2.0 cc. to only 0.42 (*cf* Fig. 10). Even the injection of 2.0 cc of angiotonin did not cause constriction of sufficient degree to stop the blood flow. The response of the small arterioles to angiotonin was as great and in some instances greater than that of the larger ones.

The arteriolar constriction produced by small amounts of angiotonin (0.2 cc) was not followed, after return of the arterioles to their control diameters, by dilatation as was the case with larger injections. For example, the injection of 1.5 cc of angiotonin caused an arteriole 35 microns in diameter to constrict to 0.5 its original diameter. This arteriole returned to its control diameter

50 minutes following the injection. Within 8.3 minutes it had increased to 1.3 its original diameter, and this dilatation lasted until 16.3 minutes after the injection

The walls of the arterioles became thicker when they constricted in response to angiotonin (*cf* Figs 5, 9, 10, and 14), indicating that such narrowing was not secondary to constriction of larger arterioles outside of the chambers

*Venules*—Angiotonin in amounts up to 0.5 cc. did not produce any visible effect upon the venules. When the amount injected was increased to 1.0 cc., however, it caused, in most instances, a slight venular constriction. Thus 1.0 cc. of angiotonin caused a venule having a control diameter of 28 microns to constrict to 0.86 its original diameter

The degree of constriction of the venules was somewhat greater with greater amounts of angiotonin. Thus, while in the above experiment, 1.0 cc. caused the venule to constrict to 0.86 its original diameter, 2.0 cc. caused a similar venule to constrict to 0.67 its original diameter

Except for such changes in diameter, the venules did not respond visibly to angiotonin

*Capillaries*—The capillaries did not react visibly to angiotonin. No capillary constriction was observed, the lumens of the capillaries remaining open at all times (Figs. 6 and 7)

#### *Reaction of the Vessels to Tyramine and Methylguanidine Sulfate*

Tyramine and methylguanidine always caused arteriolar constriction when doses of 1.5 mg of the former and 7.0 mg of the latter were injected. The constriction became maximal in 0.8 to 1.5 minutes with tyramine, and 0.8 to 1.2 with methylguanidine. Return to their original diameters occurred in about the same time (3.0 to 7.0 minutes). The degree of maximal constriction varied from 0.33 to 0.87 of the control diameters for tyramine and from 0.30 to 0.82 for methylguanidine. Isopressor amounts of both tyramine and methylguanidine, usually, but not invariably, produced greater vasoconstriction than angiotonin (compare the arteriolar constriction shown in Fig 14 with that in Figs 16 and 18)

Tyramine and methylguanidine usually did not cause constriction of the venules in the amounts injected. In one of 5 experiments slight venular constriction was observed with both tyramine and methylguanidine.

No response of the capillaries to either substance was observed.

#### *Reaction of the Vessels to Epinephrine and Pitressin*

Epinephrine and pitressin always caused arteriolar constriction when doses of 0.0015 mg to 0.10 mg of the former and 0.6 unit to 1 unit of the latter were

injected Constriction became maximal in 0.5 to 2.0 minutes with both substances

Amounts of epinephrine and pitressin isopressor with 0.2 cc of angiotonin caused much greater arteriolar constriction (compare the arteriolar constriction shown in Figs 12 and 20 with that in Fig 14) At no time did the injection of 0.2 cc of angiotonin cause constriction to the point of interruption of the circulation, whereas constriction to this extent occurred in 4 out of 7 injections of the isopressor amount of epinephrine, and in 5 out of 6 injections of the isopressor amount of pitressin

Both epinephrine and pitressin caused constriction of longer duration than that produced by the isopressor amount of angiotonin Following the injection of 0.2 cc of angiotonin the arterioles returned to their original diameters within approximately 3 minutes, following 0.003 mg of epinephrine not until 10 minutes, and after  $\frac{3}{4}$  unit of pitressin not until longer than 24 minutes

As with angiotonin the constriction of the small arterioles was as great proportionately as that of larger ones, and in some cases greater

In contrast to the effect of increasing the amount of angiotonin above 0.2 cc, increasing the amount of epinephrine above 0.003 mg caused much more vigorous and prolonged constriction Although this is probably also true of pitressin, the data are insufficient

As compared with the arteriolar constriction produced by isopressor amounts of tyramine and methylguanidine, epinephrine and pitressin caused much more (compare the constriction shown in Figs 12 and 20 with that in Figs 16 and 18)

Both epinephrine and pitressin caused constriction of the venules, the degree of constriction being greater with larger amounts, but not exceeding 0.33 the control diameter in any instance The degree of venular constriction was greater than that caused by the isopressor amount of either angiotonin, tyramine, or methylguanidine

A typical experiment with epinephrine demonstrates that the venular narrowing was not due to arteriolar narrowing, but was an active constriction In this instance, 0.0025 mg of epinephrine caused arteriolar constriction which stopped the blood flow for 4.3 minutes During this time the venules did not become narrower Venular constriction began after the arterioles had begun to relax and the blood flow had started

Neither epinephrine nor pitressin caused active capillary constriction, the lumens of the capillaries remaining open at all times Following injections which stopped the circulation for 5 minutes or longer by constriction of the arterioles, sticking of leukocytes to the walls of the capillaries increased from phase 1 to phase 2 of the Clark and Clark (11) scale Otherwise no changes were noted

## DISCUSSION

The evidence obtained by direct observation of the effects of renin and angiotonin on the blood vessels of normal rabbit's ears indicates that in moderate doses they produce active vasoconstriction in the arterioles, and in large doses slight constriction of the venules besides. The capillaries remain unaffected. The blood flow is maintained. The action of angiotonin was indistinguishable from that of renin except maximal constriction of the arterioles occurred earlier with angiotonin and relaxation was more rapid. Methylguanidine sulfate and tyramine have somewhat similar actions. All of these pressor agents contrast sharply in their action with epinephrine and pitressin, which cause severe vasoconstriction and reduction of blood flow in amounts which elicit similar rises in arterial pressure.

This suggests that the elevated arterial pressure with maintenance of peripheral blood flow caused by administration of angiotonin, renin, tyramine, and methylguanidine is due to their action on the heart as well as on the arterioles. Augmentation of the force of the heart beat by direct action on the myocardium, increase in the rate of filling, or both, would account for the increased action of the heart. Direct action of angiotonin on the heart is strongly suggested by the perfusion experiments of Hill and Andrus (12) and Lorber and Visscher (13).

In rabbits large doses of angiotonin are required to produce active venular constriction. The rise in venous pressure would aid in increasing return of blood to the heart. In human beings the rise in venous pressure is marked, and decrease in vital capacity occurs (Wilkins and Duncan (6)), suggesting that in man the action on the venules may be more marked than in rabbit's ears. However, the action on large veins with more developed muscle may be greater in rabbits than that on the relatively small venules studied.

The renal vessels appear to be more sensitive to the vasoconstrictor action of angiotonin than the vessels of the ear. This is suggested by the fact that even with moderate elevation of arterial pressure Corcoran and Page (4) found marked renal vasoconstriction and reduction of blood flow when either renin or angiotonin was injected. Pitressin, on the other hand, has a much more variable effect on the renal circulation, sometimes increasing and sometimes decreasing it, while always eliciting severe vasoconstriction in the peripheral vessels.

The evidence is clear both from clinical observation of hypertensive patients and from Kapp, Friedland, and Landis' (14) study of the effect of experimentally induced hypertension in rabbits on skin temperature, that blood flow in the peripheral tissues is not significantly reduced. Angiotonin in contrast with epinephrine and pitressin can produce hypertension without reduction of peripheral blood flow.

The observations made in this investigation may be added to those which strengthen the view (15) that the renin-angiotonin vasopressor system has characteristics consistent with those required of a substance or substances concerned in the genesis of chronic arterial hypertension

#### SUMMARY

1 Both renin and angiotonin in small doses cause constriction of the arterioles in the ears of normal rabbits, as seen directly with the microscope. Capillaries appear unaffected while venules exhibit slight or no constriction with small doses and moderate constriction with large doses. The flow of blood through the tissues is not reduced except when very large doses are administered. Tyramine and methylguanidine sulfate in isopressor amounts act somewhat similarly.

2 Isopressor amounts of epinephrine and pitressin, by contrast, elicit severe vasoconstriction of arterioles lasting longer than that due to angiotonin, and flow of blood is sharply reduced or abolished altogether. The degree of venular constriction was also greater, while the capillaries remained unaffected.

3 The vasoconstrictor action of angiotonin on peripheral vessels in moat chambers in normal rabbit's ears is indistinguishable from that of renin, except that it is more rapid.

#### CONCLUSIONS

As judged by study of the blood vessels in moat chambers in the ears of normal rabbits, angiotonin and renin elevate arterial pressure with little or no reduction of blood flow by causing constriction of arterioles and augmenting the force of the heart beat. Tyramine and methylguanidine sulfate act somewhat similarly. In contrast, epinephrine and pitressin in isopressor amounts elevate arterial pressure by causing arteriolar vasoconstriction, but the constriction is severe enough to reduce or abolish blood flow. Angiotonin, unlike epinephrine or pitressin, acts on blood vessels of the rabbit's ear in a manner not inconsistent with that required of a substance capable of producing chronic hypertension.

#### BIBLIOGRAPHY

- 1 Landis, E. M., Montgomery, H., and Sparkman, D., *J. Clin. Inv.*, 1938, 17, 189
- 2 Page, I. H., and Helmer, O. M., *Proc. Centr. Soc. Clin. Research*, 1939, 12, 17
- 3 Page, I. H., and Helmer, O. M., *J. Exp. Med.*, 1940, 71, 29
- 4 Corcoran, A. C., and Page, I. H., *Am. J. Physiol.*, 1940, 130, 335
- 5 Herrick, J. F., Corcoran, A. C., and Essex, H. E., *Am. J. Physiol.*, in press
- 6 Wilkins, R. W., and Duncan, C. N., *J. Clin. Inv.*, 1941, 20, 442
- 7 Abell, R. G., and Clark, E. R., *Anat. Rec.*, 1932, 53, 121
- 8 Abell, R. G., *Anat. Rec.*, 1937, 69, 11

- 9 Clark, E. R., Clark, E. L., and Rex, R. O , *Am. J Anat* , 1936, 59, 123
10. Clark, E. R., and Williams, R. G , *Am. J Anat* , 1934, 55, 47
- 11 Clark, E. R., and Clark, E. L., *Am J Anat* , 1935, 57, 385
12. Hill, W H P , and Andrus, E. C., *Proc Soc Exp Biol and Med* , 1940, 44, 213
- 13 Lorber, V , and Visscher, M B , *Am J Physiol* , 1941, 53, 177
- 14 Kapp, F , Friedland, C. K , and Landis, E. M., *Am J Physiol.* 1941, 131, 710
- 15 Page, I. H , *J Mount Sinai Hosp* , 1941, 8, 3

## EXPLANATION OF PLATES

### PLATE 7

FIG 1 Photomicrograph showing the normal appearance of a living arteriole and venule in the bay of a moat chamber, 28 minutes before the intravenous injection of 0.2 cc of renin. The grey blur in the lumens of the vessels is caused by circulation of the blood. The arrows indicate the direction of blood flow. *A*, arteriole, *V*, venule.  $\times 168$

FIG 2 Photomicrograph of the same vessels shown in Fig 1, 2.5 minutes following the injection of 0.2 cc renin. This was the time of maximal arteriolar constriction produced by the renin. The grey blur in the lumens of the vessels shows that the flow of blood through them did not stop. As shown in this photomicrograph, the arteriolar wall became thicker during constriction.  $\times 168$

FIG 3 Photomicrograph of the same vessels shown in Figs 1 and 2, 2.5 minutes following the injection of 0.2 cc Ringer's solution. This injection did not cause arteriolar constriction (compare with Figs 1 and 2).  $\times 168$

FIG 4 Photomicrograph showing the normal appearance of a branching arteriole and a venule in the bay of a moat chamber, 26 minutes before the intravenous injection of 1.0 cc of angiotonin. The arrows indicate the direction of blood flow. *A*, arteriole, *V*, venule.  $\times 337$

FIG 5 Photomicrograph of the same vessels shown in Fig 4, 1.0 minute following the injection of 1.0 cc of angiotonin. This was the time of maximal arteriolar constriction produced by the angiotonin. As shown in this photomicrograph, the arteriolar wall became thicker during constriction. The flow of blood was not interrupted.  $\times 337$

FIG 6 Photomicrograph of a capillary plexus in the same chamber as the vessels shown in Figs 4 and 5, taken 6 minutes before the injection of 1.0 cc of angiotonin. This plexus received its blood from one of the terminal ramifications of the left branch of the arteriole shown in Figs 4 and 5. The walls of the capillaries can be seen, and the blur in their lumens indicates blood flow, the direction of which is shown by the arrows. The actual diameter of these capillaries was approximately 9 microns.  $\times 337$

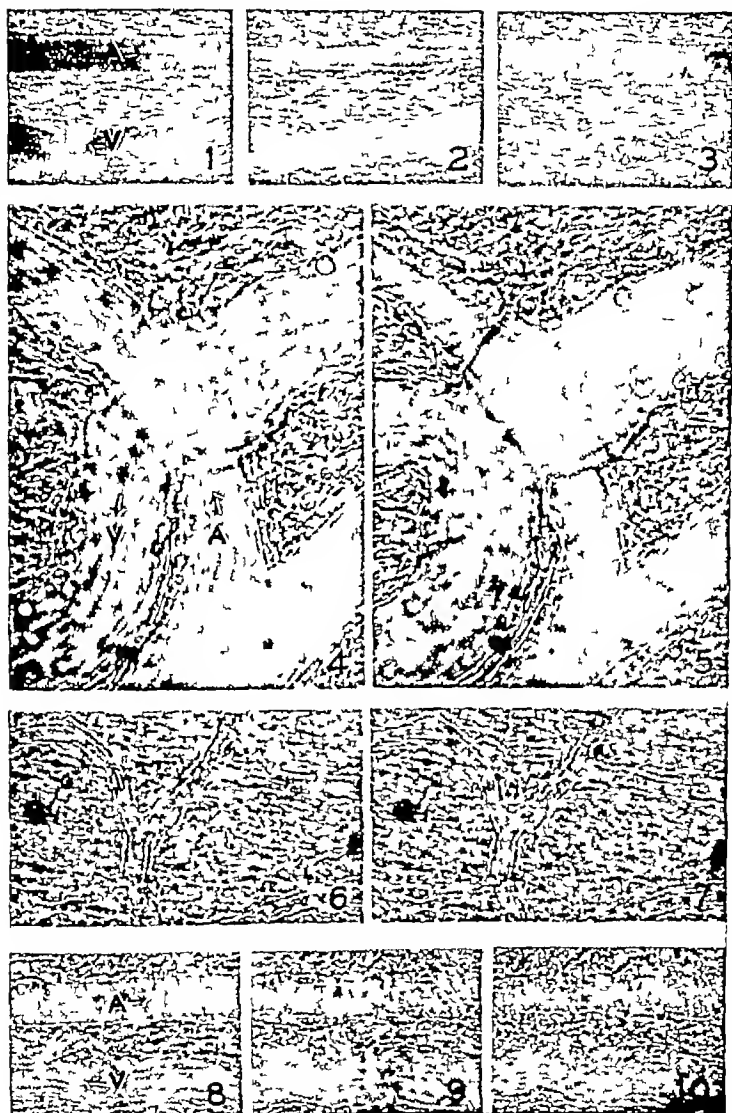
FIG 7 Photomicrograph of the same capillary plexus shown in Fig 6, taken 1.0 minute following the injection of 1.0 cc of angiotonin. This was the time of maximal arteriolar constriction (*cf* Fig 5). The flow of blood in the capillaries was not stopped, as shown by the blur in their lumens, and the capillaries did not constrict.  $\times 337$

FIG 8 Photomicrograph showing the normal appearance of an arteriole and venule in the bay of a moat chamber, 42 minutes before the injection of 1.0 cc. of angiotonin. The direction of blood flow is shown by the arrows. *A*, arteriole, *V*, venule.  $\times 230$

FIG 9 Photomicrograph of the same vessels shown in Fig 8, 0.9 minute after the injection of 1.0 cc of angiotonin. The photomicrograph shows the maximal degree of arteriolar constriction produced by this injection. The flow of blood was not stopped.  $\times 230$

FIG 10 Photomicrograph of the same vessels shown in Figs 8 and 9, 1.6 minutes following the injection of 2.0 cc. of angiotonin. The photomicrograph shows the maximal degree of arteriolar constriction produced by the angiotonin. The flow of blood was not stopped, and the arteriolar constriction was not proportionately greater than that produced by 1.0 cc. of angiotonin (compare with Fig 9).  $\times 230$





(Abell and Page Reaction of blood vessels to p-)

## PLATE 8

FIGS 11 to 20 Photomicrographs of living arterioles and venules in the bay of a moat chamber, showing the effect upon the vessels and the circulation of the intravenous injection of isopressor amounts of epinephrine, angiotonin, tyramine, methylguanidine sulfate, and pitressin. Figs 11, 13, 15, 17, and 19 are controls for 12, 14, 16, 18, and 20, respectively. The latter photographs, *i.e.*, 12, 14, etc., were taken at the time of maximal arteriolar constriction in all instances. *A* and *A*<sub>1</sub>, arterioles, *V*, venule.  $\times 230$

FIG 11 Normal appearance of the vessels 60 minutes before injection of 0.003 mg of epinephrine. The arrows indicate the direction of blood flow.

FIG 12 The same vessels 10 minutes following the injection of 0.003 mg of epinephrine. The arterioles have constricted to the point of stopping the blood flow. Stationary erythrocytes, in rouleaux formation, can be seen within the venule.

FIG 13 The same vessels 21 minutes following the above injection of epinephrine. The arterioles are slightly dilated, due to the epinephrine. This photomicrograph was taken 70 minutes before injection of 0.2 cc of angiotonin.

FIG 14 The same vessels 12 minutes following the injection of 0.2 cc of angiotonin. The arterioles have constricted, but not to the point of stopping the blood flow.

FIG 15 The same vessels 18 minutes after the above injection of angiotonin. This photomicrograph was taken 4 minutes before the injection of 1.5 mg of tyramine.

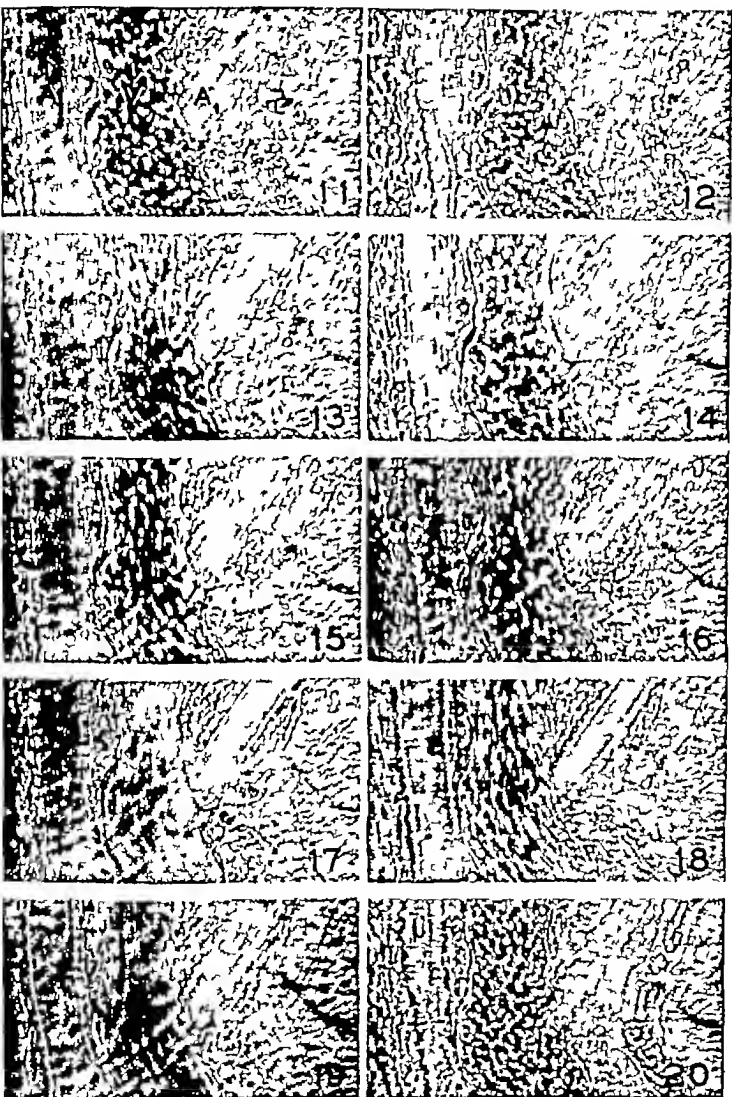
FIG 16 The same vessels 0.7 minute after the injection of 1.5 mg of tyramine. The arterioles have constricted, but not to the point of stopping the circulation.

FIG 17 The same vessels 23.5 minutes after the above injection of tyramine. This photomicrograph was taken 4 minutes before the injection of 70 mg of methylguanidine sulfate.

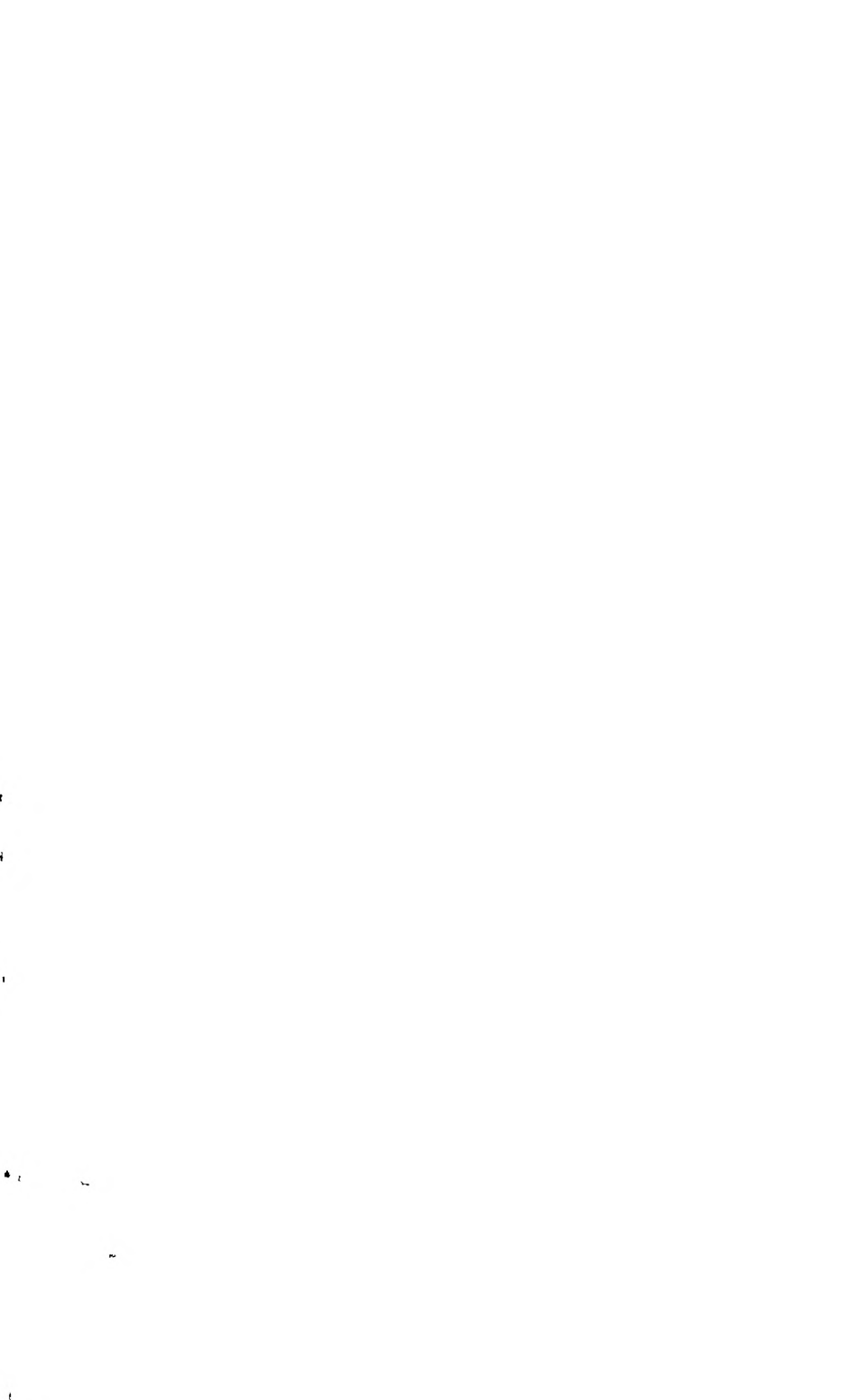
FIG 18 The same vessels 1.5 minutes after the injection of 70 mg of methylguanidine. The arterioles have constricted, but not to the point of interrupting the blood flow.

FIG 19 The same vessels 27.0 minutes following the above injection of methylguanidine. This photomicrograph was taken 8.5 minutes before the injection of  $\frac{3}{4}$  unit of pitressin.

FIG 20 The same vessels 1.1 minutes after the injection of  $\frac{3}{4}$  unit of pitressin. The arterioles have constricted to the point of stopping the circulation. Stationary erythrocytes, in rouleaux formation, can be seen within the venule.



(Abell and Page Reaction of blood vessels to pressor agents)



## HUMAN ALLERGY TO MAMMALIAN SERA

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In a previous communication report was made of a study of twenty two patients found to be allergic to one or more mammalian sera (1). The findings there reported may be summarized as follows. Skin tests (scratch method) were performed on these patients with seven to fourteen mammalian sera, namely those of the horse, cow, dog, guinea pig, hog, rat, rabbit, mouse, sheep, cat, porpoise, elephant, opossum, and monkey. The tests gave the following results. Seven patients were sensitive to horse serum but not to any of the other sera with which they were tested. Seven were sensitive, to some degree, to all the mammalian sera with which they were tested. Three were sensitive, to some degree, to all the mammalian sera with which they were tested except one. Several were sensitive to two, three, or four sera but not to the others with which they were tested. In Table I are shown the results of tests on the four patients included in the present study.

Skin tests performed with serial dilutions of sera on those patients who were sensitive to several or all the mammalian sera with which they were tested indicated that the degrees of hypersensitiveness to the various sera varied considerably in some patients while in others these degrees of hypersensitiveness were remarkably similar. Local passive transfer tests indicated that positive skin reactions to the various sera were often but not invariably accompanied by transferable reagents.

In those cases in which there were reactions to only one serum the hypersensitiveness is apparently species-specific. In other cases, however, in which there were reactions to several or all the sera with which tests were made, several questions arise. Is the hypersensitiveness in these cases also species-specific? Did these patients become sensitized to these various sera by exposure to each serum individually or is it possible that exposure to one mammalian serum may result in hypersensitiveness not only to that particular serum but also to several or many other mammalian sera? These questions are particularly applicable to those cases in which there were positive tests to the serum of animals such as the guinea pig, opossum, porpoise and elephant—animals with which these patients had, in all probability, no previous contact either by way of respiratory tract, alimentary tract, skin, or parenteral in

TABLE I  
*Direct Skin Reactions on Patients*

Scratch method Serum diluted with equal volume of glycerine

Case No	Clinical diagnosis	Horse dander	Serum of											
			Horse	Cow	Dog	Guinea pig	Hog	Rat	Rabbit	Sheep	Cat	Porpoise	Frog	Chicken
16	Perennial hay fever and asthma	++	++	++	++	++	++	++	++	++	++	++	+	—
18	Seasonal hay fever	+	++	—	++	++	++	++	++	++	++	++	++	—
21	Seasonal hay fever	—	++	++	++	+	+	—	+	++	++	++	++	—
22	Asthma	—	++	++	++	++	++	++	++	++	++	++	++	—

+ = small reaction

++ = moderate reaction

+++ = large reaction

++++ = very large reaction

All gave negative reactions to human serum

jection. A number of authors have reported crossed reactions to mammalian sera in experimental animals (5)

#### EXPERIMENTAL

In order to obtain further evidence studies were made on the serum of four patients by the method of *in vitro* neutralization of antibodies and subsequent local passive transfer, as described by Walzer (2). In order to prevent chemical contamination (mixing) of allergens special precautions were taken in the cleansing of glassware and when syringes were used for intradermal tests and antibody neutralization a new syringe and needle were set aside and used for each individual animal serum.

The reagin-bearing serum of the patient 0.50 cc. and the neutralizing animal serum, 0.50 cc. of 1-100 dilution, were drawn into a 1.00 cc. tuberculin syringe thoroughly mixed, and refrigerated in the syringe until the following day. This mixture was then injected intradermally, 0.10 cc. into each of eight (or nine) skin sites into a person not allergic to any of the sera used. The sites were marked accurately with ink and at a later time, usually after 1 to 3 days each site was tested with a different serum 0.02 cc. intradermally, as indicated in Tables II to V. The controls, as indicated in the tables, consisted of (1) chicken serum 1-100 dilution, 0.02 cc., injected into skin sites previously injected with a mixture of the patient's reagin bearing serum plus mammalian serum (2) the patient's serum plus chicken serum, refrigerated and injected into skin sites which were later tested with the various mammalian sera and also with chicken serum (3) the various mammalian sera, 1-100 dilution 0.02 cc., injected into previously uninjected (normal) skin sites of the same recipient on whom the tests were being done.

Only one mammalian serum reagin bearing serum mixture was injected into a given recipient on the same day in order to guard against the possibility of one mammalian serum diffusing from its site of injection and neutralizing antibodies at some other injection site—antibodies which had previously been mixed with some other mammalian serum. The possibility of neutralization of antibodies by allergens absorbed from the alimentary tract was considered but it was found that the eating of cooked beef (chiefly striated muscle) between the time of injections of the reagin bearing serum and subsequent skin test did not interfere with the local passive transfer reaction to cow serum.

Experiments involving *in vitro* neutralization and passive transfer of reagins are subject to certain difficulties, among which were noted

1. Certain persons are poor recipients, i.e., they do not readily accept local passive transfer of hypersensitiveness.

2. The site of passive transfer may be partially refractory for several days after injection of the reagin-bearing serum.

3. Excess allergen, from the allergen reagin mixture, may be absorbed from the injection site and may neutralize reagins at a distant skin site, including those of the positive controls, which, in these experiments were placed in the opposite arm.

4. Scrupulous cleanliness of glassware must be observed in order to prevent mixing of allergens. It is best to reserve a separate syringe for each allergen.

TABLE II  
*Antibody Neutralization, Case 16*

Serum of patient plus serum of	Incubated injected into recipient, skin site tested with serum of								
	Horse	Cow	Dog	Guinea pig	Hog	Rat	Rabbit	Sheep	Chicken
Horse	—	—	++++	+++	—	—	++	++	—
Chicken	++	+	++++	+++	±	+	++	++	—
Cow	++++	—	++++	++++	+++	+++	+++	+++	—
Chicken	++++	++	++++	++++	+++	+++	+++	+++	—
Dog	—	—	—	—	—	—	—	—	—
Chicken	+++	+	++++	++	+	+	++	++	—
Guinea pig	++++	++	++++	—	—	—	+++	++	—
Chicken	++++	++	++++	++	+	—	+++	++	—
Hog	++++	—	++++	+++	—	++	+++	+++	—
Chicken	++++	++	++++	+++	+	++	+++	+++	—
Rat	++++	+	++++	+	++	—	+++	++	—
Chicken	++++	++	++++	+++	++	++	+++	++	—
Rabbit	++	—	++++	++	+	+	—	++	—
Chicken	+++	—	++++	++	+	++	+	++	—
Sheep	++++	—	+++	+++	+	+	+++	—	—
Chicken	++++	+	++++	++++	+++	++	+++	++	—

TABLE III  
*Antibody Neutralization, Case 22*

Serum of patient plus serum of	Incubated injected into recipient, skin site tested with serum of								
	Horse	Cow	Dog	Guinea pig	Hog	Rat	Rabbit	Sheep	Chicken
Horse	—	±	+++	+	+	—	++	++	—
Chicken	++	±	++++	++	++	++	++	++	—
Cow	++++	—	++++	++++	+++	+++	++	+++	—
Chicken	++++	+	++++	+++	+++	+++	+++	+++	—
Dog	—	—	—	—	—	—	—	—	—
Chicken	+	±	++++	++	+	+	++	+	—
Guinea pig	+	—	++++	—	±	—	+	+	—
Chicken	++	±	++++	++	++	++	++	+++	—
Hog	+++	+	++++	++	—	—	++	++	—
Chicken	++++	+	++++	++	+	+++	+++	++	—
Rat	++	—	++++	+	—	—	+	+	—
Chicken	+++	±	++++	++	++	+++	++	++	—
Rabbit	++	±	+++	+	—	—	—	±	—
Chicken	++	±	+++	++	+	+	++	++	—
Sheep	+++	—	++++	+	±	—	+	—	—
Chicken	+++	—	++++	+++	++	++	++	++	—



TABLE IV  
*Antibody Neutralization, Case 21*

Serum of patient plus serum of	Incubated, injected into recipient, skin site tested with serum of							
	Horse	Cow	Guinea pig	Hog	Rat	Rabbit	Sheep	Chicken
Horse	-	++	-	-	-	-	+++	-
Chicken	+	++	+	+	-	++	+++	-
Cow	-	-	-	-	-	-	+++	-
Chicken	+	++	+	+	-	-	+++	-
Guinea pig	-	+	-	-	-	-	++++	-
Chicken	±	++	±	±	-	±	++++	-
Hog	±	+	-	-	-	-	+++	-
Chicken	+	++	-	±	-	+	+++	-
Rat	Patient not sensitive to rat serum							
Chicken								
Rabbit	+	++	-	-	-	-	++++	-
Chicken	+	++	-	-	-	+	++++	-
Sheep	-	-	-	±	-	-	-	-
Chicken	++	+++	+	+	-	+	++++	-

TABLE V  
*Antibody Neutralization Case 18*

Serum of patient plus serum of	Incubated, injected into recipient, skin site tested with serum of							
	Horse	Cow	Guinea pig	Hog	Rat	Rabbit	Sheep	Chicken
Horse	-	-	-	-	-	-	-	-
Chicken	++++	-	+++	++	++	++	+	-
Cow	Patient not sensitive to cow serum							
Chicken								
Guinea pig	++++	-	-	-	-	++	-	-
Chicken	++++	-	+++	++	++	+++	+++	-
Hog	+++	-	+++	-	-	++	±	-
Chicken	++++	-	+++	++	++	+++	++	-
Rat	++++	-	+	-	-	-	+	-
Chicken	++++	-	+++	+++	++	++	++	-
Rabbit	++++	-	-	-	-	-	-	-
Chicken	++++	-	++	++	++	++	+	-
Sheep	+++	-	±	-	-	+	-	-
Chicken	++++	-	+++	++	++	++	++	-

For these and other reasons it was often necessary to repeat the transfers several times in order to obtain satisfactory results. The results of many experiments had to be discarded entirely. When precautions are observed and the proper controls carried out, however, it is believed that the results are reliable and warrant certain deductions.

#### FINDINGS

As indicated in Tables II to V the hypersensitiveness was partially species-specific as proven by the fact that, in each case, one particular mammalian serum (dog in cases 16 and 22, horse in No. 18, sheep in No. 21) neutralized reagins for all mammalian sera with which tests were made, whereas the other mammalian sera neutralized reagins for themselves alone or for themselves plus one or several additional sera but not for all sera. The ability of any particular mammalian serum to neutralize reagins for other mammalian sera varied with the different reagin-bearing sera, thus indicating that the reagins for any one particular mammalian serum differed in different individual patients.

#### DISCUSSION

The neutralization by one allergen of antibodies for another allergen may be explained in three ways. (1) By assuming that antibodies are not absolutely specific but may react not only with the allergen which stimulated their production but also with other allergens having a closely related chemical structure. Evidence that this is one correct interpretation has been presented by Landsteiner working with artificial, conjugated compounds (5). (2) By assuming that immunologically related substances, such as mammalian sera, are mixtures of two or more allergens and contain one or more of these allergens in common. (3) By assuming that a single molecule may contain multiple allergenic determinants and that different chemical compounds obtained from different sources contain one or more of these determinants in common, as suggested by the work of Hooker and Boyd (6).

In several of the cases reported here it will be observed that antibodies for a given mammalian serum, obtained from one patient, were neutralized by several other mammalian sera, whereas antibodies for the same serum, obtained from another patient, were not entirely neutralized by the same sera. This fact definitely proves that the antibodies for this particular mammalian serum obtained from two different sources are not identical. These differences in antibodies may be partially explained by assuming that the antibodies were brought into existence as the result of stimulation by different allergens, in one case, for example, by an injection of horse serum, in another by the eating of mutton, and in a third by the inhalation of dog dander, and so forth.

Several of the original twenty-two patients included in the previous report were sensitive to only one of the sera with which they were tested. Others

were sensitive to several sera in varying degree, the reactions ranging from strongly positive to certain sera to negative to one or more other sera. The degrees of sensitivity to these different sera varied greatly in different patients, certain sera gave strongly positive reactions in some patients and negative reactions in others. It follows that the (fixed tissue) antibodies in these patients are different. The absorption experiments described above have demonstrated that the antibodies, in some cases, are not entirely species-specific. These facts suggest that the antibodies for a given mammalian serum, obtained from different patients, are directed against (specific for) different allergenic elements in that serum.

The fact that several of these patients were found to be sensitive to all the mammalian sera with which they were tested, except human serum, suggests the possibility of an allergen common to all mammalian sera except that of man. This assumption logically calls for another, namely, the existence of an allergen common to all mammalian sera except that of the horse, etc. Thus each mammalian serum would be assumed to be characterized not only by a species-specific factor but also by the *absence* of an allergen common to all other mammalian sera, and the *presence* of innumerable common allergens—a conclusion which is very improbable, if not absurd. This difficulty may be overcome, however, by assuming the existence of a relatively small number of allergenic complexes or determinants, present in the various mammalian sera in different numbers and combinations, certain of the complexes being absent in certain sera and present in other sera. One may suppose that mammalian sera contain many allergenic elements. Among these there is at least one for each species which is species-specific. The others vary in their distribution among different species. Certain of these elements have a wide distribution, while others have a more limited distribution. The serum of any one species of mammal is lacking in one or more of the elements which are present in the sera of some of the other species. One would have to assume that different human individuals react differently in their response to the same complex of allergenic stimuli (3). This assumption, however, is in agreement with the clinical fact that different individuals in the same environment, inhaling the same substances (pollens, for example) become sensitized to different substances or to the same substances in different degrees. It is also in agreement with the experiment of Landsteiner, *et al* (4) (in another type of allergy) in which two chemicals, paranitrosodimethylaniline and dinitrochlorobenzene were applied to the skin of man. Certain individuals became sensitized only to the former, others only to the latter, while others became sensitized to both but in varying degree to each.

This hypothesis explains (1) positive reactions to many mammalian sera in persons who have probably had contact with only one or a few of these sera, (2) positive reactions to certain sera, such as those of the guinea pig, porpoise,

opossum, and elephant, contact with which (even through the medium of the respective danders) is very rare in the general population, (3) positive skin reactions to horse serum in persons in whom there is no history of contact with horses and no history of injection of horse serum preparations. In such cases the hypersensitiveness may have resulted from the eating of (partially cooked) beef, pork, mutton, or other mammalian meat, or perhaps from the inhalation of the dander of the cat, dog, or other mammal. This hypothesis does not, of course, exclude the possibility of species-specific sensitivity to several different mammalian sera in the same individual, nor does it deny the possibility that antibodies may react with substances closely related chemically to those which stimulated their production.

#### SUMMARY

Four patients allergic to many mammalian sera were found to have circulating, skin-sensitizing antibodies for these sera. A study of these antibodies by *in vitro* neutralization and subsequent local passive transfer showed that, in the case of each patient, one particular mammalian serum neutralized antibodies for all sera whereas other mammalian sera neutralized antibodies for themselves alone or for themselves plus one or several additional sera but not for all sera. The possibility of multiple common allergenic determinants in mammalian sera is discussed.

#### BIBLIOGRAPHY

- 1 Simon, F. A., *J. Allergy*, 1941, **12**, 610
- 2 Walzer, M., and Bowman, K., *J. Allergy*, 1930, **1**, 464
- 3 Coca, A. F., Walzer, M., Thommen, A. A., *Asthma and hay fever in theory and practice*, Springfield, Illinois, Chas. C. Thomas, 1931, 57
- 4 Landsteiner, K., Rostenberg, A., and Sulzberger, M. B., *J. Inv. Dermat.*, 1939, **2**, 25
- 5 Landsteiner, K., *The specificity of serological reactions*, Springfield, Illinois, Chas. C. Thomas, 1936, chapters 2 and 4
- 6 Hooker, S. B., and Boyd, W. C., *J. Immunol.*, 1934, **26**, 469

## STUDIES ON LYMPHOGRANULOMA VENEREUM

### I DEVELOPMENT OF THE AGENT IN THE YOLK SAC OF THE CHICKEN EMBRYO

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PLATES 9 TO 11

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The demonstration that the method of yolk sac inoculation, first used successfully by Cox (1) in his investigations on *Rickettsiae*, could be applied with success to the growth of the agent of lymphogranuloma venereum (2) has stimulated more extensive investigations of this disease and its causative agent (3-12). Amongst other studies which have been made is one of the nature of the development of the agent in the cells of the yolk sac. This has been the subject of a preliminary communication elsewhere (13). The purpose of the present paper is to describe this development in detail with regard both to morphological changes and to concomitant changes in the infective titre of the yolk sac.

The first description of apparently specific inclusions in connection with lymphogranuloma venereum was given by Gamna in 1923 (14) and again in 1924 (15) when the observations were confirmed by Favre (16). Both these observers noted in mononuclear cells from infected lymph nodes, whether in the natural human disease or in experimental disease in guinea pigs, cytoplasmic inclusions varying in size from those which were barely visible to others  $4.5\mu$  in diameter. These might be multiple in one cell, varied in size, and were often either vacuolated or contained an acidophilic center and basophilic periphery. They were not found in other conditions or in normal lymph nodes. Similar bodies were seen in lymphogranuloma venereum by Todd (17). In publications in 1933 (18) and 1938 (19) Findlay cast doubt on the virus nature of these bodies because many of them give a positive reaction for thymonucleic acid, but in retrospect it seems probable that they do represent different stages in the development of the agent.

In 1927 Gay Prieto described small bodies which seemed to be specific (20). These appeared both within and between the monocytes surrounding the abscesses; they were of  $1\mu$  or less in size, were mostly round, oval or semilunar and were metachromatic. Twelve or more might appear in the cytoplasm of a single cell. In 1933 Findlay (18) also described bodies similar to those of Gay Prieto. These were found in human material and also in the experimental disease in monkeys, guinea pigs and mice. They were from 1 to  $4\mu$  in diameter and were found in lymphocytes, in plasma

cells, or lying free. They were basophilic and the smaller ones sometimes occurred in large masses.

In 1935 Miyagawa and his associates described for the first time "granulo-corpuscles" about  $0.3\mu$  in diameter which resembled closely the elementary bodies of other viruses (21). These bodies were found in monocytes, leucocytes, and glial cells in the brains of intracerebrally infected monkeys. They were solitary, in pairs, or in groups, did not give a Feulgen reaction, and were negative with Gram stain. Similar bodies were found in all human material from cases of lymphogranuloma venereum. In a subsequent paper (22) similar bodies were described in monocytes, glial cells, and neurones of intracerebrally infected mice. In advanced lesions they increased markedly in number so that they came finally to fill the infected cell. Although not mentioned in the text, the illustrations for both these papers suggest that the specific bodies may vary in size. The presence of these bodies was soon confirmed by other investigators, for example Nauck and Malamos (23), who noted that they resembled closely the elementary bodies of psittacosis in their staining reactions with Giemsa stain. In the preparations of these authors paired forms were common. The elementary bodies often occupied vacuoles in the cell cytoplasm or were embedded in a (with Giemsa) reddish violet matrix.

Several filtration studies with Elford gradocol membranes were carried out by various investigators and gave results in keeping with the microscopic findings of Miyagawa and his associates (21). Thus by such filtration Broom and Findlay arrived at a size of from  $125$  to  $175m\mu$  for the elementary bodies (24).

Differences in size of the virus bodies and in their staining reactions soon were noted (25, 26), and in 1938 Findlay and his colleagues suggested that the virus might undergo a developmental cycle (27). In the early lesions in intracerebrally infected mice large bodies were seen  $0.4$  to  $0.7\mu$  in diameter. These stained bluish violet with Giemsa and were often irregular in shape, suggesting fission. Intermediate forms between these and the reddish violet elementary bodies of  $0.1$  to  $0.175\mu$  were seen. The large forms occasionally occurred massed together into plaques. Malamos (28) also noted larger blue staining bodies in the early stages of the infection of tissue cultures of rabbit corneal epithelium. These larger bodies increased in size and, while homogeneous at first, were later seen to contain elementary bodies. These larger plaques became vacuolated and might break up into shreds and uneven fragments. In a later study Findlay and his colleagues gave a more detailed description of the suggested cycle of development of the agent in the brains of infected mice (19). Following intracerebral inoculation no virus could be seen in smears for some hours. The initial bodies which were seen were larger than elementary bodies. Since dumb-bell like division forms were noted it appeared that these large bodies divided. Compact masses of large bodies might result from which individual bodies might break off, enter other cells, and give rise to elementary bodies but no decision was reached as to whether the elementary bodies themselves divided, although pairs and short chains were noted. When sufficiently numerous in the cytoplasm, the elementary bodies formed collections within vacuoles with definite limiting membranes, the membranes might eventually rupture and liberate the elementary bodies which could then infect new cells.

Amongst others who have noted more than one form of the virus bodies are Schoen

(29), and Gey and Bang (30) Schoen (29) noted that the first bodies to be seen inside vacuoles in the ependymal cells of infected mouse brains at 48 hours were 2 to 3  $\mu$ . By 4 days the bodies had become smaller and might be bacilliform. Gey and Bang (30) used a tissue culture of fibroblasts from human thyroid and grew the virus for as long as 7 months. After 7 days small vesicles were seen in the fibroblasts and these later increased in size. The small vesicles contained bodies about 1  $\mu$  in diameter but the larger vesicles which occupied the whole cell, were filled with bodies 0.2  $\mu$  in diameter which showed brownian movement. No large inclusions other than the vesicles were seen. The latter were thought to represent response of the cells to the presence of the virus.

### *Technique*

All the studies of development described below have been carried out with one strain of lymphogranuloma venereum, namely that obtained originally through the courtesy of Dr W. L. Fleming and termed by us J. H. However, similar morphological elements have been seen in the other three strains with which we have worked, one of which was isolated by inoculation of human pus into the yolk sac.

All inoculations have been made into the yolk sac of 6 day old chicken embryos (1) and have been of 1 ml. volume. Suspensions have been made by shaking infected yolk sacs for 30 minutes on a machine with sufficient beef heart infusion broth (pH 7.6) to produce a 10 per cent dilution. These yolk sacs had been freed of most of their yolk by careful draining but had not been washed. Throughout the investigation the titre of the virus has remained almost unchanged both for embryos by the yolk sac route with an L<sub>50</sub> of  $10^{-9}$ , and for mice by the intracerebral route with an L<sub>50</sub> of 1 to 416. In studying the development of the agent in the yolk cells, different dilutions of infected yolk sac have been used as inoculum as will appear below but a dilution of  $10^{-1}$  or  $5 \times 10^8$  infective doses has given us the most significant results. In titrating the amounts of virus present in the yolk cells at different stages of development the yolk sac method of inoculation has been used and eggs surviving for 15 days after inoculation (i.e. to the point of hatching) have been opened and examined for the presence of virus both by smear and, in many cases, by section. The titres given are therefore those of persistent infection rather than mortality although in most cases these have corresponded. Of 368 eggs which were opened on the 15th day after infection and found to be alive, 16 or 4.4 per cent have been found by smear or section to be infected. In 567 eggs whether dead or alive found negative on smear 42 or 7.4 per cent have been found positive on section. The yolk sac method has also been used in estimating the amount of virus present in embryonic tissues other than the yolk sac.

In the morphological studies use has been made both of smears or impressions and of sections. Smears and impressions are made by smearing or gently impressing on a clean glass slide a small fragment of yolk sac from which excess free yolk has been removed on a gauze sponge. For Gram or Macchiavello stain these smears or impressions have been heat fixed. For Giemsa stain whether the slow or the rapid method be used they have been fixed in 95 per cent methyl alcohol. Material for

paraffin section has been fixed in Zenker's or Helly's fluid After the former fixation staining has been carried out with eosin and methylene blue or with Giemsa After fixation with Helly's fluid Noble's stain, as described by Yanamura and Meyer (31), has been employed

### RESULTS

As has been indicated elsewhere (2), during the earlier stages of infection after yolk sac inoculation, virus could be demonstrated, by intracerebral inoculation of mice, only in the yolk sac and to a lesser degree in the yolk The brain, viscera, and chorio-allantois contained no virus demonstrable by this method If the infection were permitted to progress until the embryo was moribund or dead and titration were made in the yolk sac results were obtained as shown in Table I The titre of the original inoculum and the conse-

TABLE I

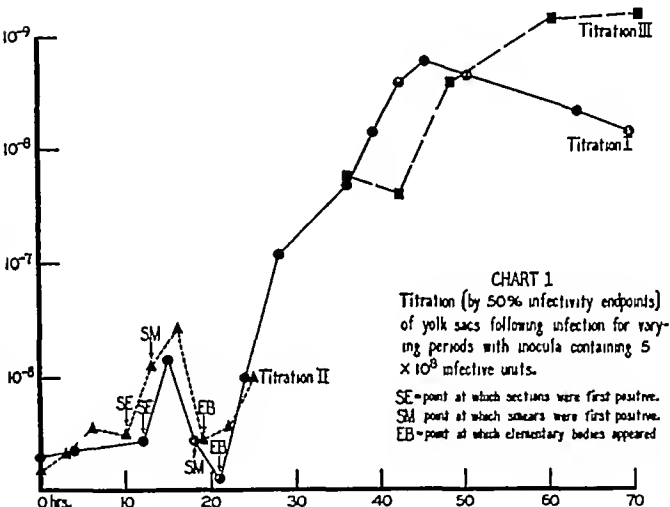
	Average 50 per cent endpoint of infectivity	Outside limits of titre in different experiments
Yolk sac	$10^{-8.42}$	$10^{-7}$ to $10^{-9}$
Yolk	$10^{-7.0}$	$10^{-6}$ to $10^{-8}$
Chorio-allantois and amnion	$10^{-1.95}$	$10^{-1}$ to $10^{-4}$
Whole embryo less membranes	$10^{-2.77}$	$10^{-1}$ to $10^{-4}$
Brain	$10^{-1.24}$	$10^{-1}$ to $10^{-3}$
Skin and muscle	$10^{-2.59}$	$<10^{-2}$ to $10^{-4}$
Lungs	$10^{-2.25}$	$10^{-1}$ to $10^{-3}$
Liver, kidney, and spleen	$10^{-3.75}$	$<10^{-2}$ to $10^{-5}$

quent period of survival of the embryos did not appear to be of any great importance as far as the distribution and titre of virus in the moribund or dead embryo were concerned It will be noted that the yolk contained considerable amounts of virus but always less than that found in the yolk sac, while the embryo itself or its component tissues contained much less It seemed clear from these results that the multiplication of the virus was occurring principally in the yolk sac and that the virus found in the other tissues of the embryo was due in all probability to invasion of the vessels in the highly vascularized yolk sac tissue with perhaps slight multiplication in favorable sites The presence of the virus in the yolk was due to the rupture of the infected yolk cells which, as will appear below, were often completely filled with virus bodies At no time has there been any evidence of multiplication in the yolk itself, and studies have shown that, far from multiplying in yolk removed from the egg, viable virus rapidly disappears and in most cases a starting titre of  $10^5$  to  $10^8$  infective units per ml has fallen to zero in 48 hours

For the above reasons it seemed logical to confine our investigations of the development of the agent of lymphogranuloma venereum to the yolk sac of



the embryo. The most informative results have been obtained with an inoculum of  $5 \times 10^8$  infective units, or 1 ml of a 1 in 10 dilution of a heavily infected yolk sac, and frequent killing of embryos thereafter for both titration and morphological studies. Representative titration curves are shown in Chart 1 which also includes certain important data from the morphological studies. Table II contains the pertinent data.



In both of these studies large numbers of eggs were inoculated by the yolk sac method with 1 ml. of a  $10^{-1}$  dilution of a heavily infected yolk sac. At successive short time intervals thereafter 3 eggs were opened and the yolk sacs removed. Small fragments of each yolk sac were used to prepare smears and impressions, larger fragments were fixed in both Zenker's and Helly's fluids, and the remainders of the yolk sacs (approximately an equal amount from each of the 3 eggs) were pooled and shaken with sufficient beef heart infusion broth to give a 1 in 10 original dilution. From this dilution appropriate other dilutions were prepared and 10 eggs inoculated with each appropriate dilution by the yolk sac technique. On death of any of these test embryos, or after 15 days incubation in the case of those surviving (i.e. at hatching time) smears were made from the yolk sacs and these were stained with Giemsa and Macchiavello stains and examined for virus. In those cases in which there remained any doubt after examination of the smears, sections were prepared and examined

As will be seen from the titrations there was but slight increase in the titre of virus up to 12 hours, during the next 4 hours however the rise in titre was rapid, being approximately tenfold. This rise was followed by an abrupt fall to levels equal to those found at the commencement of the experiment. A second rise began at about 22 hours and was more sustained than the early rise. The maximal titre was reached in about 44 hours and later the titre leveled off or actually decreased slightly, this decrease being due presumably to the titration of less susceptible eggs which were the only ones to survive for 60 or more hours.

TABLE II  
50 Per Cent Endpoints of Infectivity

Titration I		Titration II	
Time from inoculation to testing of yolk sac	Result	Time from inoculation to testing of yolk sac	Result
hrs		hrs	
0	$10^{-5.29}$	0	$10^{-5.17}$
4	$10^{-5.36}$	3	$10^{-5.33}$
12	$10^{-5.44}$	6	$10^{-5.55}$
15	$10^{-6.16}$	10	$10^{-5.5}$
18	$10^{-5.43}$	13	$10^{-6.11}$
21	$10^{-5.11}$	16	$10^{-6.43}$
24	$10^{-6.0}$	19	$10^{-5.45}$
28	$10^{-7.09}$	22	$10^{-5.57}$
36	$10^{-7.71}$	25	$10^{-6.0}$
39	$10^{-8.17}$	Titration III	
42	$10^{-8.6}$	36	$10^{-7.77}$
45	$10^{-8.81}$	42	$10^{-7.62}$
63	$10^{-8.36}$	48	$10^{-8.59}$
69	$10^{-8.19}$	60	$10^{-9.21}$
		70	$10^{-9.25}$

Some indication of the morphological changes which accompanied these changes in titre are given in Chart 1. These studies of morphology were, as has been pointed out above, carried out both by smear and by section. Up to the first 6 hours occasional virus bodies, elementary bodies, or others, could be seen in the smear or more rarely in sections. From their staining reactions and morphological characters it was clear that these bodies represented virus of the original inoculum. The period during which such bodies were found was always followed by a short period in which no virus could be observed in either section or smear, and this in turn was succeeded by the initial stages of the developmental cycle of the virus. These initial stages were always observed first in section and later in smear and, for the sake of convenience, the changes in the former will be described first. The picture of a cyclical de-

velopment which is given is open to the objection that it is obtained by the study of static preparations and must therefore be to some degree guesswork. However, it may be emphasized that the picture is a composite one which has been obtained by the examination of several hundred yolk sacs in which tissue the virus is very plentiful and extremely easy to see. Moreover the relationship of time to the stage of the development of the virus has been so precisely worked out that it is now possible to foretell with accuracy the picture which will be found in eggs opened at any given time after receiving a given number of infective units of virus.

Following the disappearance of the originally inoculated virus, new virus bodies, which might or might not be surrounded by halos, appeared in the yolk cells where they lay close to the walls, at about 10 to 12 hours after original inoculation. Although in every instance the original inoculum consisted almost entirely of elementary bodies which showed after staining by the usual methods an average diameter of 400 m $\mu$ , the initial virus bodies seen in the yolk cells had a diameter of about 1  $\mu$  or more than twice that of the original virus particles. Since these initial bodies when first seen were very scanty and consisted of single bodies or at most pairs, it seems probable that the earlier stages of the cycle were overlooked on account of the small size of the original infecting units. These appeared to make use of the first 10 to 12 hours to increase in size until they were readily visible (Fig 1). These initial bodies divided much like cocci to form pairs (Fig 2) tetrads, and small groups (Fig 3). By the time that these small groups (as in Fig 3) had begun to appear, definite structural arrangements might be seen. The virus bodies appeared to be arranged within a vesicle with a limiting membrane which was more clearly defined in some instances than in others. The virus bodies might or might not be arranged close to the surface of this membrane and were already seen to be embedded in a thin matrix. Differential stains such as Noble's stain (31) showed that all of these virus bodies apparent at this time stained green with methylene green as did the thin matrix. No virus which had retained the basic fuchsin and therefore stained red appeared until later. Within a short time of the appearance of these small groups one began to see besides an augmentation in number of these initial bodies, a further definite increase in size (Fig 4). Thus by 16 hours bodies of 2  $\mu$  in diameter were to be found and by 18 to 20 hours bodies 4  $\mu$  in diameter were apparent. The matrix in which the bodies were embedded had become denser. By this time, moreover definite structural differentiation might be seen within these larger bodies. With eosin methylene blue stain or Giemsa, some of the bodies of between 2 and 4  $\mu$  were seen to be vacuolated (Fig 5) while with Noble's stain at 18 hours a few of the larger green-staining masses were seen to contain one or more smaller muddy brown bodies which were undoubtedly bodies retaining the basic fuchsin seen through the dense green-staining surrounding material. By 20 hours definite bright red elementary bodies within large green bodies or plaques, or lying free were to be seen. This is shown in Fig 6 in which a body about 3.5  $\mu$  in diameter contains besides a small vacuole two small red bodies about 600 to 800 m $\mu$  in diameter embedded in the homogeneous dense green capsule. The plaques, already mentioned above, seemed to be produced by a steady augmentation in size of the larger bodies and only rarely, if at all, by the fusion of two or more bodies.

Several such plaques might appear in one vesicle (Figs 7 and 8). They might reach a diameter of  $4.5\mu$  without showing any definite vacuolation when stained with eosin-methylene blue (Fig 9) but most of the bodies of  $3\mu$  or greater were markedly vacuolated (Figs 8, 10, and 11). Individual plaques might reach a diameter of at least  $7\mu$  (Fig 8). In most cases with eosin-methylene blue nothing could be seen in the vacuoles of the large bodies or plaques but occasionally, as in Fig 8, one might see quite definite little bodies of the size of elementary bodies in the vacuoles, and with the Noble stain many of the plaques were found to contain few or many red bodies of all sizes (Fig 12). However, after the examination of many preparations one is forced to the conclusion that the plaques when they become large and show vacuoles are very fragile and in most cases lose their content of elementary bodies during the handling necessary in the production of the fixed sections. In Fig 11 it would appear that the central plaque, which is obviously disintegrating, has liberated large numbers of elementary bodies which in this case are still to be seen closely surrounding it.

The changes seen in the first 18 to 20 hours may be summarized as follows. The first bodies were seen in the yolk cells at 10 to 12 hours after inoculation and at this time were more than twice as large as elementary bodies. During the next 6 hours these bodies increased in number (to 40 or more) and size (up to  $4\mu$ ) and came to occupy small vesicles in which they were embedded in a thin matrix. Between 18 and 20 hours the bodies increased still more in size and formed plaques which might be  $7\mu$  in diameter. These latter showed vacuoles and with certain stains were seen to contain small granules of elementary body size. By their disintegration elementary bodies were set free and the first cycle might be said to have been completed. While therefore in many cases the first cycle might continue for 30 hours or longer, in some cases it took only 18 hours, this being the shortest period that we have noted. It must be emphasized that all the diameters given are those of fixed and stained virus bodies.

The liberated elementary bodies in many cases escaped from the affected cell and entered new cells to initiate new cycles of the same type as that described above.

The first appearance of this new cycle, as heralded by single or paired initial bodies close to the walls of otherwise normal yolk cells, was at 28 to 30 hours, i.e. 10 to 12 hours after the "reinoculation" with new elementary bodies, thus confirming the 10 to 12 hour "silent" period noted in the first cycle. If, however, they did not enter new undamaged cells, the history of the elementary bodies seemed to be different. New small vesicles were formed in which the elementary bodies divided for the most part as such so that the vesicles came to contain enormous numbers of elementary bodies embedded in a thin matrix. Just below the limiting membrane bodies of  $1\mu$  or greater might occur but they were less numerous than the elementary bodies. Fig 13 to 16 show the development of these vesicles. From small size (Fig 13) they came to occupy the whole cell (Fig 14). Later many cells are filled (Fig 15) and finally, at the point of death of the embryo, nearly all the cells are so affected (Fig 16). It is

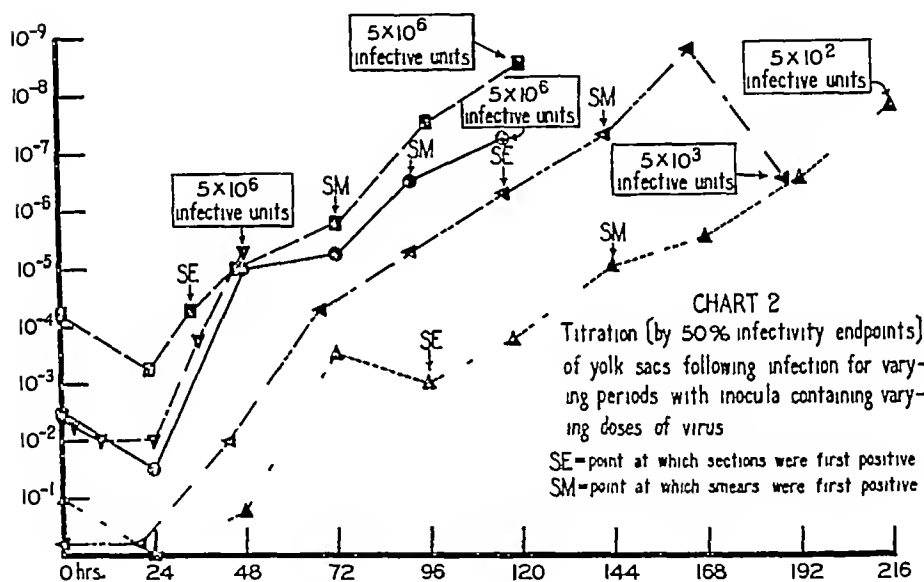
difficult to distinguish individual elementary bodies in the central mass but larger bodies may be seen close to the periphery of the vesicles.

As has been pointed out above, virus appeared in the smears or impressions from 3 to 6 hours later than it did in the sections. This was undoubtedly due to the fact that in smears the virus was derived by liberation from yolk cells damaged usually by the progress of infection and more rarely by the manipulation used in making the preparations. In the early hours virus was too scanty in the cells, and cell damage was so slight, that no bodies appeared in the smears. Once virus did appear in these preparations however, it went through the same cycle as that seen in the sections.

At about 14 hours one began to see single virus bodies and even small groups similar to that shown in Fig. 17. The similarity of this to the group shown in Fig. 3 (in a section) is immediately apparent. Slightly later the groups were larger and by 20 hours were seen to contain bodies of the size of elementary bodies (Figs. 18 and 19). With Macchiavello stain the majority of these bodies stained blue up to 18 hours but even at 13 hours red, large bodies were seen. Later the proportion of red bodies to blue increased but at all times some blue bodies even of the size of elementary bodies were to be seen. Intact plaques were not seen in smears and any plaques were rare, but every now and then plaques in the process of disintegration were seen (Fig. 20). Scattered fragments of matrix were seen in the early stages, *s.e.* at 13 hours, but later larger masses of matrix in the process of disintegration were to be seen (Figs. 21 and 23). In Giemsa stains virus bodies could be seen in these masses, albeit with difficulty but with Macchiavello stain red or blue virus bodies stood out clearly against the pale blue of the matrix (Fig. 23). In much later stages, *s.e.* at 48 hours elementary bodies predominated but larger bodies were still to be seen. The so called dumbbell forms described for psittacosis were seen and appeared to be forms undergoing division and separation (Fig. 24). At the time of death elementary bodies formed by far the majority of forms seen (Fig. 25). In some smears yolk cells containing large numbers of elementary bodies were seen (Fig. 26) or others in which the masses of elementary bodies remained intact although dislodged from the yolk cell (Fig. 27). Frequently one saw monocytes containing virus bodies (Fig. 28) but this would appear to represent only phagocytosis of the virus particles. A photograph (Fig. 29) of colonies of staphylococci growing in the yolk cells is inserted for comparison of size.

With Noble's or Macchiavello's stain the majority of elementary bodies forming a new inoculum retained the basic fuchsin and stained bright red. However as has been pointed out above the initial bodies were invariably green with Noble's stain, and no red bodies were seen until about 18 hours when brownish red bodies (or red bodies apparently partly obscured in green capsular material) were seen. With Macchiavello's stain red initial bodies might appear in smears albeit rarely as early as 13 hours. Eighteen hours is the time of the first appearance of elementary bodies and it might appear from this that the elementary bodies were the essential virus bodies, that they always retain the basic fuchsin when exposed to it but that in the early stages of the cycle they were concealed in a dense capsule which stained with methylene green (or blue) so that they could not be seen until the capsule became

larger and less dense. That this simple explanation will not suffice, however, is shown by the fact that at no stage were all of the elementary bodies red (and this is particularly true with Macchiavello's stain), and furthermore that red bodies might occur of at least  $2\mu$  in diameter, that is, as large or larger than the initial bodies. It is the opinion of the authors that the initial bodies are furnished with a capsular material of their own manufacture (as opposed to the matrix which appears to be derived from the cell) and that in the early stage both virus and capsule stain with methylene green or blue. Later, due to metabolic changes, much of the virus retains the basic fuchsin while the capsule continues to stain green or blue. This faculty of the virus to stain either with basic fuchsin or with methylene blue in Macchiavello's stain is shown by



those bacteria that we have studied. The metabolic changes responsible are not understood. The nature of either capsules or matrix has not been determined, it is not glycogen and in this respect the virus resembles that of psittacosis (32) and not that of trachoma (33).

When one correlates the changes in titre with the morphological appearances the following facts emerge. During the "silent" period of 10 to 12 hours during which no virus is observed in the yolk cells, only a very slight rise in titre occurs. Following the appearance of initial bodies, and coincident with the visual evidence of multiplication, the titre rises abruptly until about 16 or 18 hours. Then, at the time when elementary bodies first appear in section and larger numbers of virus bodies appear in the smear, the titre drops abruptly and may take 9 to 12 hours to regain its former level. It appears

probable that the appearance of elementary bodies is related to the rupture of many yolk cells and the discharge of virus into the yolk where most of it is lost in titrations of the yolk sacs. This loss into the yolk obscures, for several hours, the continued increase within the yolk cells, but this period is finally succeeded by another and more prolonged one in which the titre again rises steeply.

When smaller inocula are used as the initiating dose the results obtained are less spectacular and informative. It is very difficult to follow the results as closely as can be done during the short period from inoculation to death which follows the giving of a large inoculum. Two features which are usual in the titration curves obtained by the use of smaller inocula (Chart 2) merit attention. The first occurs in the first 24 hours and is a drop in titre below that obtained immediately following inoculation. It would appear to be due to a loss of infectivity on the part of many of the inoculated virus bodies. The second, which occurs at varying times from 48 to 96 hours after inoculation, depending on the size of the original inoculum, is a break in the steep rise in the titration curve, or even a decrease in titre, seemingly corresponding to the break occurring in the curve following the large inocula (Chart 1) which has been shown to occur at the conclusion of a developmental cycle and the consequent liberation of elementary bodies into the yolk.

#### DISCUSSION

Developmental cycles of equal or less complexity have been described in connection with other viruses. Thus Thygeson found larger initial bodies 0.3 to 0.8  $\mu$  in diameter and smaller elementary bodies at a later stage in both inclusion blennorrhoea (34) and trachoma (35, 36). As in lymphogranuloma venereum, division forms were frequent, in the vesicles or large colonies of elementary bodies the larger forms tended to be at the periphery, and the larger bodies stained blue while the elementary bodies stained reddish blue with Giemsa. Thygeson noted the resemblance to the picture seen in psittacosis but pointed out (36) that the matrix surrounding the virus bodies in trachoma and inclusion blennorrhoea could be shown to contain glycogen (33) which the matrix in psittacosis does not. We ourselves have not been able to demonstrate glycogen in the matrix in lymphogranuloma venereum.

Less resemblance to that of the agent of lymphogranuloma venereum is seen in the developmental cycle of vaccinia described by Bland and Robinow (37) but certain features of this latter cycle are reminiscent of the former.

When however attention is turned to the life cycle of the virus of psittacosis it is found that the resemblance between this and that described above for lymphogranuloma venereum is very striking.

Bedson and Bland were the first to draw attention to different developmental forms in psittacosis (32). Observing the spleens of infected mice they described, besides

the elementary bodies which stained deep purple with Giemsa, larger bodies of  $1\mu$  or more in diameter which might be circular or oval, appeared in pairs indicating division, and stained light blue with Giemsa. In addition, moreover, there were homogeneous plaques several  $\mu$  in diameter of material staining with Giemsa like the virus bodies, which apparently divided to give rise to the larger  $1\mu$  bodies. These in turn divided until the stage of elementary bodies was again reached, the whole cycle from elementary body back to the same stage taking 48 to 72 hours. In later papers (38, 39) the sequence of events was studied more carefully. It was found to be regular and completion of the cycle occupied 48 hours. The infecting elementary bodies gave rise to larger  $1\mu$  bodies very soon after entering the cells. These larger bodies multiplied as such and formed colonies embedded in a matrix. Finally the large forms by subdivision gave rise to very large numbers of elementary bodies. No conclusion was reached as to whether the elementary bodies multiplied as such. When Bland and Cantú (40) followed the actual process in tissue culture (of chick lung epithelium) they noted first, at 8 hours, round or oval 5 to  $10\mu$  plaques which increased in size. Although these plaques appeared at first to be homogeneous, actually they contained many bodies  $1\mu$  in diameter. Later still at 18 to 24 hours the matrix became less dense and forms intermediate in size between the  $1\mu$  bodies and elementary bodies could be seen and by 72 hours nothing but elementary bodies was seen, embedded in a very light matrix. When these colonies of elementary bodies became enormous they eventually burst and set free numerous elementary bodies. Like Gey and Bang with lymphogranuloma venereum (30) they noted that the elementary bodies of psittacosis which lay in a light matrix surrounded by a definite limiting membrane, exhibited violent brownian movement. No development occurred outside the cells. Levinthal (41) also described the developmental cycle in chick embryonic tissue culture. He noted two types of cycle (a) as it occurs in normal cells with large forms and plaques exactly as described by Bedson and Bland, and (b) as it occurs in damaged cells in which case the elementary bodies as such divide to form enormous colonies (vesicles) of virus bodies. Levinthal also noted what he termed involution forms, *i.e.* forms like dumbbells or others which were pale and vacuolated. Yanamura and Meyer (31) more recently have again investigated the developmental cycle in psittacosis and have confirmed in the main the results of the earlier investigators. Particularly when one examines the illustrations given in the above papers on psittacosis is one struck by the marked similarity between the picture in this disease and that in lymphogranuloma venereum. All the developmental forms described for the one disease can be exactly duplicated in the other.

The finding of the close morphological similarity between the agents of lymphogranuloma venereum and psittacosis is of great interest in view of other resemblances which exist between these viruses. Thus Rake, Eaton, and Shaffer (12) have shown that antigenic and tropistic similarities exist between the two viruses and others which appear to belong to the same group, and Jones, Rake, and McKee (11) have drawn attention to the fact that the carrier state may be as frequent and persistent in lymphogranuloma venereum as it is in psittacosis.



Our own studies described above have confirmed most of the description of the cycle as given by Findlay and have filled in many details. However, we have at no time seen any evidence to lead us to believe that the plaques are formed by aggregation of large bodies, rather one has been able to follow their formation by steadily increasing size of individual bodies, and the evidence for direct multiplication of elementary bodies as such would seem to be very strong since, for example, pairs and short chains are of common occurrence. On the whole our interpretation of the different picture seen at different stages after infection resembles most closely that given by Levinthal (41) for the cycle of development of the virus of psittacosis. In addition to the morphological changes we have been able to demonstrate constant changes in infective titre in the affected tissue and to correlate such changes to the morphological picture.

Bedson (38) and Bedson and Bland (39) believed that the large bodies in psittacosis had less virulence for mice than had the elementary bodies and gave evidence in support of this claim. There is no reason to believe that in the case of lymphogranuloma venereum any such decreased virulence of large bodies for the embryo occurs and, in fact, a consideration of the facts points against it. Thus, as is shown in Chart 1 or in Table II, an original inoculum of  $5 \times 10^8$  infective units gives a titre of approximately  $10^{8.2}$  on immediate titration of the yolk sac. It is known that the infective units in this original inoculum are almost all elementary bodies. They cannot be seen in the yolk cells in sections prepared immediately after inoculation nor is any virus seen until about 10 hours when the larger initial bodies appear. It seems more than probable that such initial bodies, which are always single, when first seen and proceed shortly to divide, are derived by increase in size of the original elementary bodies. And this is borne out by the fact that the infective titre of the yolk sac remains approximately unchanged during this early period. It certainly does not decrease as would be the case if these initial bodies had a virulence less than those of the elementary bodies from which they are derived.

#### SUMMARY

Making use of the fact that the cells of the yolk sac of the developing embryo are readily infected with the agent of lymphogranuloma venereum and that the virus bodies can be readily observed in these cells because of the structure of the latter, the development of this agent has been followed at short intervals. It has been found to go through a regular cycle of development similar to that described for psittacosis in the spleen and less fully for lymphogranuloma venereum in the brain of infected mice. The development as observed microscopically can be shown to run parallel to changes in the infective titre of the yolk sac as tested in other eggs.

## BIBLIOGRAPHY

- 1 Cox, H R , *Pub Health Rep , U S P H S* , 1938, 53, 2241
- 2 Rake, G , McKee, C M , and Shaffer, M F , *Proc Soc Exp Biol and Med* , 1940, 43, 332
- 3 Shaffer, M F , Rake, G , and McKee, C M , *Proc Soc Exp Biol and Med* , 1940, 44, 408
- 4 McKee, C M , Rake, G , and Shaffer, M F , *Proc Soc Exp Biol and Med* , 1940, 44, 410
- 5 Grace, A W , Rake, G , and Shaffer, M F , *Proc Soc Exp Biol and Med* , 1940, 45, 259
- 6 Rake, G , Shaffer, M F , Jones, H P , and McKee, C M , *Proc Soc Exp Biol and Med* , 1941, 46, 300
- 7 Harrop, G A , Rake, G W , and Shaffer, M F , *Tr Am Clin Climat Assn* , 1940, 56, 154
- 8 Harrop, G A , Rake, G , and Shaffer, M F , *Tr Assn Am Physn* , 1941, 56, 101
- 9 Rake, G , Shaffer, M F , Grace, A W , McKee, C M , and Jones, H P , *Am J Syph , Gon , and Ven Dis* , 1941, 25, 687
- 10 Shaffer, M F , Rake, G , Grace, A W , McKee, C M , and Jones, H P , *Am J Syph , Gon , and Ven Dis* , 1941, 25, 699
- 11 Jones, H P , Rake, G , and McKee, C M , *Proc Soc Exp Biol and Med* , 1941, 48, 318
- 12 Rake, G , Eaton, M D , and Shaffer, M F , *Proc Soc Exp Biol and Med* , 1941, 48, 528
- 13 Rake, G , Jones, H , and Shaffer M F , *Am J Path* , 1941, 17, 460
- 14 Gamna, C , *Arch sc med* , 1923, 46, 22
- 15 Gamna, C , *Presse méd* , 1924, 32, 404
- 16 Favre, M , *Presse méd* , 1924, 32, 651
- 17 Todd, A T , *Lancet* , 1926, 2, 700
- 18 Findlay, G M , *Tr Roy Soc Trop Med and Hyg* , 1933, 27, 35
- 19 Findlay, G M , Mackenzie, R D , and MacCallum, F O , *Tr Roy Soc Trop Med , and Hyg* , 1938, 32, 183
- 20 Gay-Prieto, J A , *Actas dermo-sif* , 1927, 20, 122
- 21 Miyagawa, Y , Mitamura, T , Yaori, H , Ishii, M , Makajima, H , Okanishi, J , Watanabe, S , and Sato, K , *Japan J Exp Med* , 1935, 13, 1
- 22 Miyagawa, Y , Mitamura, T , Yaori, H , Ishii, M , and Okanishi, J , *Japan J Exp Med* , 1935, 13, 331
- 23 Nauck, E G , and Malamos, B , *Arch Schiffs- u Tropen-Hyg* , 1937, 41, 537
- 24 Broom, J C , and Findlay, G M , *Brit J Exp Path* , 1936, 17, 135
- 25 Herzberg, K , and Kobl Müller, L O , *Klin Woch* , 1937, 16, 1173
- 26 Coutts, W E , Martin, J , and Gacitua, L M , *Dermat Woch* , 1938, 107, 1404
- 27 Findlay, G M , MacKenzie, R D , and MacCallum, F O , *Nature* , 1938, 141, 877
- 28 Malamos, B , *Zentr Bakt* , 1 *Abt , Orig* , 1938, 143, 1
- 29 Schoen, R , *Ann Inst Pasteur* , 1939, 62, 260
- 30 Gey, G O , and Bang, F B , *Bull Johns Hopkins Hosp* , 1939, 65, 393

- 31 Yanamura, H Y , and Meyer, K. F , *J Infect Dis* , 1941, 68, 1
- 32 Bedson, S P , and Bland, J O W , *Brit J Exp Path* , 1932 13, 461
- 33 Rice, C. E , *Am J Ophth.*, St. Louis 1936 19, 1
- 34 Thygeson, P , *Am J Ophth* St. Louis, 1934, 17, 1019
- 35 Thygeson, P , *Arch. Ophth* , 1934 12, 307
- 36 Thygeson, P , and Richards P , *Arch Ophth* , 1938, 20, 569
- 37 Bland, J O W and Robinow, C F , *J Path. and Bact* , 1938, 48, 381
- 38 Bedson, S P , *Brit J Exp Path* 1933, 14, 267
- 39 Bedson, S P , and Bland, J O W , *Brit J Exp Path.* 1934 15, 243
- 40 Bland, J O W , and Cantu R G *J Path and Bact* , 1935, 40, 231
- 41 Levinthal, W , *Lancet*, 1935, 1, 1207

## EXPLANATION OF PLATES

## PLATE 9

- FIG 1 Single virus body Eosin-methylene blue  $\times 1200$   
FIG 2 Pair of virus bodies Eosin-methylene blue  $\times 1200$   
FIG 3 Early vesicle containing several virus bodies Eosin-methylene blue  
 $\times 1200$   
FIG 4 Larger virus bodies and groups Eosin-methylene blue  $\times 1200$   
FIG 5 Larger virus bodies, one at top vacuolated. Eosin-methylene blue  
 $\times 1200$   
FIG 6 Elementary bodies in plaque Noble  $\times 1200$   
FIG 7 Group of plaques and large bodies Eosin-methylene blue  $\times 1200$   
FIG 8 Multiple vacuolated plaques Eosin-methylene blue  $\times 1200$



## EXPLANATION OF PLATES

## PLATE 9

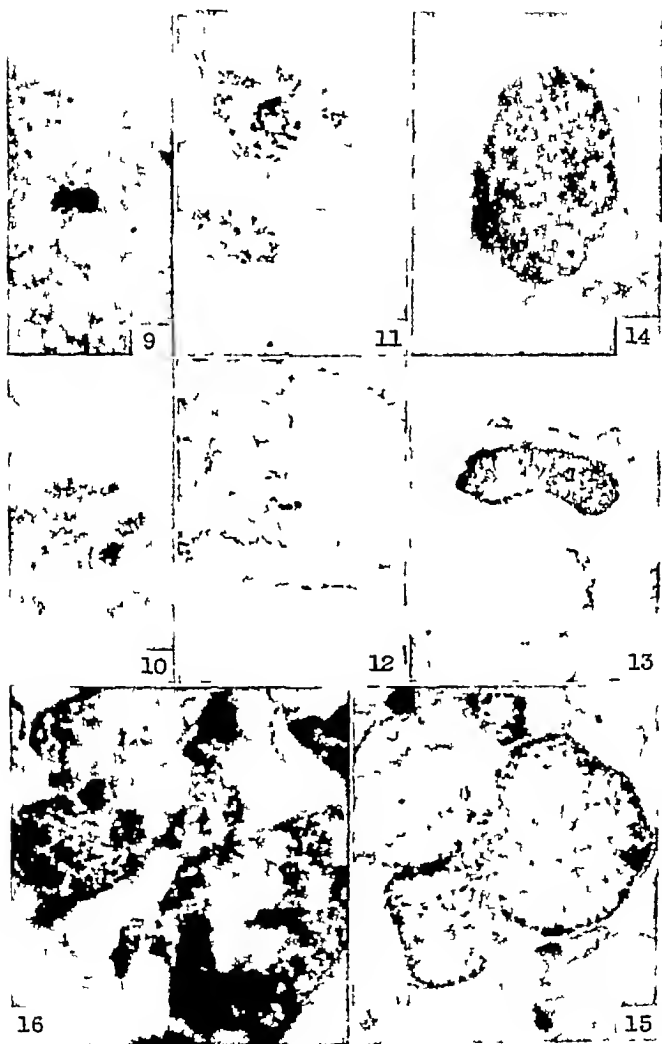
- FIG 1 Single virus body Eosin-methylene blue  $\times 1200$   
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 $\times 1200$   
FIG 6 Elementary bodies in plaque Noble  $\times 1200$   
FIG 7 Group of plaques and large bodies Eosin-methylene blue  $\times 1200$   
FIG 8 Multiple vacuolated plaques Eosin-methylene blue  $\times 1200$



PLATE 10

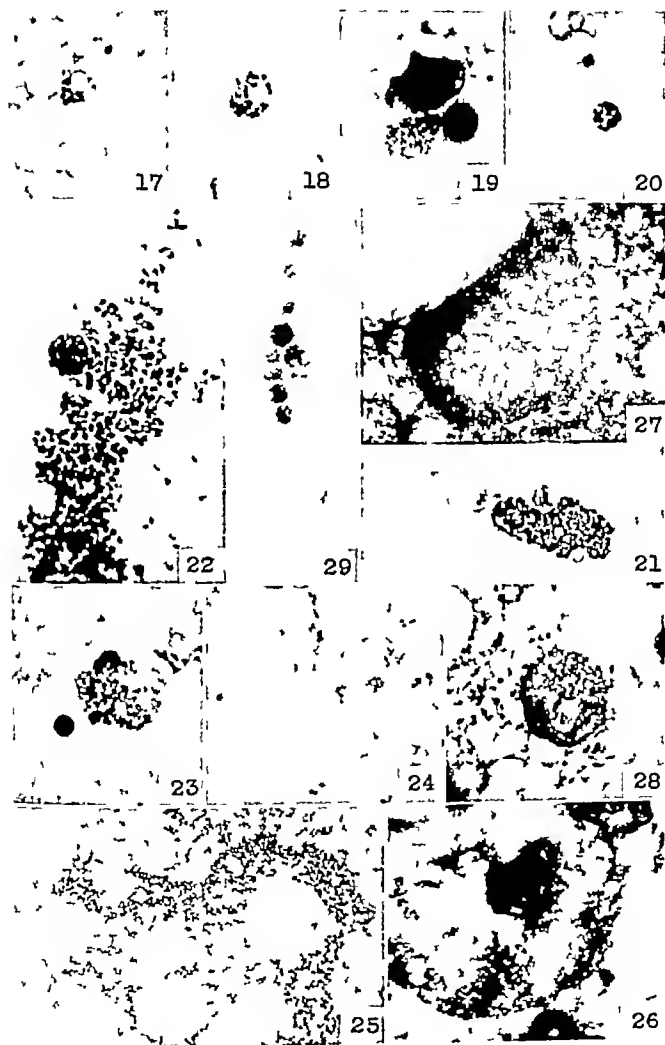
- FIG 9 Disintegrating and intact plaques Eosin-methylene blue  $\times 1200$   
FIG 10 Vacuolated plaque Eosin-methylene blue  $\times 1200$   
FIG 11 Disintegrating vacuolated plaque surrounded by elementary bodies  
Noble  $\times 1200$   
FIG 12 Virus bodies in plaque Noble  $\times 1200$   
FIG 13 Medium vesicle Eosin-methylene blue  $\times 1200$   
FIG 14 Large vesicle Eosin-methylene blue  $\times 1200$   
FIG 15 Three large vesicles Eosin-methylene blue  $\times 1200$   
FIG 16 All cells filled with virus Eosin-methylene blue  $\times 1200$





# PLATE 11

- FIG 17 Group of virus bodies in smear Giemsa  $\times 1200$
- FIG 18 Large group of virus bodies in smear Giemsa  $\times 1200$
- FIG 19 Group of elementary and larger virus bodies Smear Giemsa  $\times 1200$
- FIG 20 Disintegrating plaque Smear Giemsa  $\times 1200$
- FIG 21 Disintegrating matrix Smear Giemsa  $\times 1200$
- FIG 22 Disintegrating matrix Smear Giemsa  $\times 1200$
- FIG 23 Disintegrating matrix. Smear Macchiavello  $\times 1200$
- FIG 24 Elementary and pair virus bodies Smear Giemsa  $\times 1200$
- FIG 25 Elementary bodies Smear Giemsa  $\times 1200$
- FIG 26 Elementary bodies in yolk cell Smear Giemsa  $\times 1200$
- FIG 27 Large mass of virus from yolk cell Smear Giemsa  $\times 1200$
- FIG 28 Phagocytosed virus in monocyte Smear Giemsa  $\times 1200$
- FIG 29 Colonies of staphylococci in yolk cells Eosin-methylene blue  $\times 1200$





# SEROLOGICALLY REACTIVE POLYSACCHARIDES PRODUCED THROUGH THE ACTION OF BACTERIAL ENZYMES\*

## I. DEXTRAN OF *LEUCONOSTOC MESAENTEROIDES* FROM SUCROSE

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A preliminary paper (1) reported that a serologically reactive polysaccharide of dextran nature is produced from sucrose through the action of an enzyme or some similar heat labile agent contained in sterile filtered extracts of *Leuconostoc mesenteroides*. The object of the present paper is to describe the preparation of the sterile extracts and to compare the chemical and serological properties of the dextran formed by the bacteria free extracts with those of the dextran formed in cultures of the living bacteria.

Previous workers have reported the production of gum like material from sucrose by sterile filtrates derived from various species of spore forming bacilli. In 1910 Beijerinck (2) described the formation of "slime" on sucrose agar by filtered preparations of *Bacillus mesentericus*, he considered the active principle to be a "synthetically active enzyme" which he termed *viscosaccharase*. Harrison, Tarr, and Hibbert (3) reported that a sterile filtrate of similar bacilli formed from sucrose an alcohol precipitable material which gave opalescent solutions. Also, it is possible that the production of bacteria free "colonies" on sucrose agar plates by filtrates of sucrose broth cultures of *Bacillus fluorescens* which has been reported by Dienes (4) and others represents another manifestation of the same phenomenon. However, in none of the earlier studies were the products identified chemically or tested serologically, whereas in the present study the product is proved to be an immunologically reactive polysaccharide similar in both chemical and serological properties to the product formed in cultures of the living bacteria.

### EXPERIMENTAL

#### Materials and Methods

*Preparation of the Extracts*—The extracts utilized in the present study were made from cultures of a strain of *Leuconostoc mesenteroides* isolated in this laboratory. It gave mucoid growth on sucrose mediums and produced acid from both xylose and

\* This investigation was aided by a grant from the Ruth B. Ettinger Fund.

arabinose With this strain of *leuconostoc* the fundamental principle that serologically reactive material could be formed in the absence of the bacterial cells was demonstrable with Berkefeld filtrates of sucrose broth cultures That is, these filtrates which were apparently sterile as far as could be told by microscopic or cultural tests showed a gradual increase in opalescence and in serological reactivity when stored in the ice box. However, for a study of the formation of the polysaccharide the filtrates had the disadvantage of containing only a low concentration of the active agent in comparison to the large amounts of the preformed product That disadvantage was met by applying the principle introduced by Sevag (5) for the separation of proteins from polysaccharides when the fluids of sucrose broth cultures were shaken with chloroform most of the preformed polysaccharide remained in the supernatant, whereas the active principle which would subsequently produce the specific polysaccharide (when added to sucrose) was contained in the chloroform emulsion layer With this strain of *leuconostoc* (which has a highly soluble polysaccharide) the active agent could also be separated by salting-out procedures but the chloroform treatment was more convenient and was utilized to prepare all of the extracts used in the present experiments

Some extracts were made from the supernatant fluids of centrifuged cultures but for convenience most of them were prepared from the whole cultures without preliminary removal of the bacterial cells The usual starting material was a total of 5 one-liter lots of culture which had been grown in separate flasks for about 20 hours at 23°C, the cultures had received a large inoculum and by the time they were used had already become gummy or viscous, microscopic observation showed no evidence of autolysis or disintegration of the bacterial cells The medium in which the cultures were grown consisted of 1 per cent bacto-peptone (without meat extract or infusion), 0.5 per cent salt, and 5 per cent sucrose This medium afforded adequate growth and for the preparation of the extracts had the advantages of giving little foam when shaken and of containing only a minimum amount of material adsorbable upon chloroform

Each flask of culture was chilled, shaken by hand for 5 minutes with 25 cc of cold chloroform, and then centrifuged in the cold at 1500 R P M for 5 to 10 minutes The supernatant fluids which contained most of the serologically reactive polysaccharide and most of the bacteria were decanted from the chloroform emulsion precipitates which contained the active principle In order to get further separation from the preformed polysaccharide the emulsion material from all of the flasks was collected and washed two or three times with cold distilled water, each time the emulsion was suspended in 500 cc of water and then sedimented by low speed centrifugation and carefully separated from the wash fluid In order to free the active principle from its combination with the chloroform the washed emulsion material was treated with 500 cc. of cold 95 per cent ethyl alcohol, in which the active agent was insoluble The particles were brought into a finely dispersed state and this alcohol suspension was centrifuged in the cold at high speed for 40 minutes The alcohol was decanted and, after the tubes had drained for an hour in the refrigerator, the precipitate was extracted with 50 cc of distilled water and adjusted to about pH 7.5 with 0.1 N NaOH After removal of insoluble particles by centrifugation at high speed the extracts were filtered through Berkefeld W filters which had been

tested by the "bubbling pressure" method and found to emit air only at or above a pressure of 680 mm. of mercury. The filtered extracts were adjusted to pH 6.0 and then stored in a brine-cooled chamber at a temperature slightly below 0°C.

*Sterility Controls*—Each extract was examined carefully by microscopic and cultural methods and in no instance were any microorganisms detected. No disinfectants were added to the extract-substrate mixtures but all of the constituents had been sterilized either by filtration or by autoclaving and aseptic technique was employed in the preparation and subsequent handling. The sterility of the extract-substrate mixtures was well controlled by microscopic and cultural tests made at appropriate intervals during the incubation periods as well as at the beginning and end of the experiments. The cultural tests consisted of inoculations in sucrose peptone broth and agar slants and also in broth and agar slants enriched with sterile (filtered) unheated cane juice; all these mediums were known to be adequate for growth of *Leuconostoc* bacteria and those enriched with the unheated cane juice can be regarded as furnishing an especially rigorous test. From the results of the numerous sets of controls we feel certain that all of the observed reactions occurred in the complete absence of bacteria.<sup>1</sup>

*Polency of the Extracts*—The present paper does not include any systematic data on the minimal time and the minimal concentration of extract which are required for the production of demonstrable amounts of the polysaccharide, but some information on both those points was obtained. In respect to time, if the extract was used in dilutions of 1/2 or 1/4 in mixtures containing 5 per cent sucrose significant amounts of reactive material were regularly produced within 1 to 2 hours at either 23 or 37°C. In respect to minimal amount of extract, dilutions of 1/1000 of all and of 1/10,000 of most of them would form demonstrable amounts of the polysaccharide in test mixtures containing 5 per cent sucrose if incubated for 20 days at 23°C.

*Serological Tests*—All of the antisera were from rabbits. The dextran of the present strain of *Leuconostoc* reacts with Types 2 and 20 antipneumococcus as well as with antileuconostoc serum (6, 7) in the many comparative titrations which we have made; the range of dilutions of the dextrans which gave precipitation was usually essentially the same for those three kinds of antiserum. Hence, in most experiments of this paper the dextran produced by action of the extracts was measured on the basis of tests with only one of the antisera, usually Type 2 antipneumococcus. The dextran also reacts to some extent with Type 12 antipneu-

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<sup>1</sup> Tubes of sucrose broth if inoculated with as much as 0.5 cc. of the extracts became opalescent but the opalescence can be accepted simply as an intrinsic property of the polysaccharide product formed from sucrose by the active principle of the extracts; no bacteria were demonstrable in the opalescent solutions either by direct examination or by subculture, and no change in pH or titratable acidity was evident whereas with *Leuconostoc* bacteria an increase in acidity would have occurred. Further evidence that the opalescence did not represent microbial growth was that its development was neither more rapid nor finally greater in amount when the extracts were inoculated in sucrose mediums (broth or unheated sugar cane juice) which could support luxuriant growth of the bacteria than when the same extracts were added to aqueous sucrose solutions in which *Leuconostoc* bacteria could grow poorly if at all.

arabinose With this strain of *leuconostoc* the fundamental principle that serologically reactive material could be formed in the absence of the bacterial cells was demonstrable with Berkefeld filtrates of sucrose broth cultures That is, these filtrates which were apparently sterile as far as could be told by microscopic or cultural tests showed a gradual increase in opalescence and in serological reactivity when stored in the ice box. However, for a study of the formation of the polysaccharide the filtrates had the disadvantage of containing only a low concentration of the active agent in comparison to the large amounts of the preformed product That disadvantage was met by applying the principle introduced by Sevag (5) for the separation of proteins from polysaccharides when the fluids of sucrose broth cultures were shaken with chloroform most of the preformed polysaccharide remained in the supernatant, whereas the active principle which would subsequently produce the specific polysaccharide (when added to sucrose) was contained in the chloroform emulsion layer With this strain of *leuconostoc* (which has a highly soluble polysaccharide) the active agent could also be separated by salting-out procedures but the chloroform treatment was more convenient and was utilized to prepare all of the extracts used in the present experiments

Some extracts were made from the supernatant fluids of centrifuged cultures but for convenience most of them were prepared from the whole cultures without preliminary removal of the bacterial cells The usual starting material was a total of 5 one-liter lots of culture which had been grown in separate flasks for about 20 hours at 23°C, the cultures had received a large inoculum and by the time they were used had already become gummy or viscous, microscopic observation showed no evidence of autolysis or disintegration of the bacterial cells The medium in which the cultures were grown consisted of 1 per cent bacto-peptone (without meat extract or infusion), 0.5 per cent salt, and 5 per cent sucrose This medium afforded adequate growth and for the preparation of the extracts had the advantages of giving little foam when shaken and of containing only a minimum amount of material adsorbable upon chloroform

Each flask of culture was chilled, shaken by hand for 5 minutes with 25 cc. of cold chloroform, and then centrifuged in the cold at 1500 R P M for 5 to 10 minutes The supernatant fluids which contained most of the serologically reactive polysaccharide and most of the bacteria were decanted from the chloroform emulsion precipitates which contained the active principle In order to get further separation from the preformed polysaccharide the emulsion material from all of the flasks was collected and washed two or three times with cold distilled water, each time the emulsion was suspended in 500 cc of water and then sedimented by low speed centrifugation and carefully separated from the wash fluid. In order to free the active principle from its combination with the chloroform the washed emulsion material was treated with 500 cc of cold 95 per cent ethyl alcohol, in which the active agent was insoluble The particles were brought into a finely dispersed state and this alcohol suspension was centrifuged in the cold at high speed for 40 minutes The alcohol was decanted and, after the tubes had drained for an hour in the refrigerator, the precipitate was extracted with 50 cc of distilled water and adjusted to about pH 7.5 with 0.1 N NaOH After removal of insoluble particles by centrifugation at high speed the extracts were filtered through Berkefeld W filters which had been



tested by the "bubbling pressure" method and found to emit air only at or above a pressure of 680 mm. of mercury. The filtered extracts were adjusted to pH 6.0 and then stored in a brine-cooled chamber at a temperature slightly below 0°C.

*Sterility Controls*—Each extract was examined carefully by microscopic and cultural methods and in no instance were any microorganisms detected. No disinfectants were added to the extract-substrate mixtures but all of the constituents had been sterilized either by filtration or by autoclaving and aseptic technique was employed in the preparation and subsequent handling. The sterility of the extract-substrate mixtures was well controlled by microscopic and cultural tests made at appropriate intervals during the incubation periods as well as at the beginning and end of the experiments. The cultural tests consisted of inoculations in sucrose-peptone broth and agar slants and also in broth and agar slants enriched with sterile (filtered) unheated cane juice; all these mediums were known to be adequate for growth of *Leuconostoc* bacteria and those enriched with the unheated cane juice can be regarded as furnishing an especially rigorous test. From the results of the numerous sets of controls we feel certain that all of the observed reactions occurred in the complete absence of bacteria.<sup>1</sup>

*Potency of the Extracts*—The present paper does not include any systematic data on the minimal time and the minimal concentration of extract which are required for the production of demonstrable amounts of the polysaccharide but some information on both those points was obtained. In respect to time, if the extract was used in dilutions of 1:2 or 1:4 in mixtures containing 5 per cent sucrose significant amounts of reactive material were regularly produced within 1 to 2 hours at either 23 or 37°C. In respect to minimal amount of extract, dilutions of 1:1000 of all and of 1:10,000 of most of them would form demonstrable amounts of the polysaccharide in test mixtures containing 5 per cent sucrose if incubated for 20 days at 23°C.

*Serological Tests*—All of the antisera were from rabbits. The dextran of the present strain of *Leuconostoc* reacts with Types 2 and 20 antipneumococcus as well as with antileuconostoc serum (6-7), in the many comparative titrations which we have made the range of dilutions of the dextrans which gave precipitation was usually essentially the same for those three kinds of antiserum. Hence, in most experiments of this paper the dextran produced by action of the extracts was measured on the basis of tests with only one of the antisera, usually Type 2 antipneumococcus. The dextran also reacts to some extent with Type 12 antipneu-

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<sup>1</sup> Tubes of sucrose broth if inoculated with as much as 0.5 cc. of the extracts became opalescent but the opalescence can be accepted simply as an intrinsic property of the polysaccharide product formed from sucrose by the active principle of the extracts; no bacteria were demonstrable in the opalescent solutions either by direct examination or by subculture and no change in pH or titratable acidity was evident whereas with *Leuconostoc* bacteria an increase in acidity would have occurred. Further evidence that the opalescence did not represent microbial growth was that its development was neither more rapid nor finally greater in amount when the extracts were inoculated in sucrose mediums (broth or unheated sugar cane juice) which could support luxuriant growth of the bacteria than when the same extracts were added to aqueous sucrose solutions in which *Leuconostoc* bacteria could grow poorly if at all.

mococcus serum but since this cross reaction occurs only with relatively high concentrations of the antigen the Type 12 antiserum by itself was unsuitable for routine measurement of the product of the action of the extract

The leuconostoc antisera were produced by immunization with bacteria grown in sucrose peptone broth, none of the antisera we have obtained with leuconostoc grown on glucose mediums have been reactive with the dextran. The pneumococcus antisera had been produced by immunization with bacteria grown in infusion broth containing no added carbohydrate, with the pneumococci growth in a sucrose medium apparently is not essential in order to get an antiserum reactive with the leuconostoc dextran. It should be noted that an occasional lot of either Type 2 or 20 antiserum although of high homologous titre may lack the capacity to give the usual leuconostoc reaction (6)

### *Action on Sucrose*

A number of lots of sterile extract prepared at different times by the described procedure have been tested and all have had the capacity of forming serologically reactive material from sucrose. The extracts obviously do not represent purified solutions of the active agent but were adequate to establish the general principle of the reaction with sucrose and to permit the isolation of the purified polysaccharide product in amounts large enough for chemical as well as serological study. None of the extracts was entirely free of pre-formed polysaccharide. However, the amount contained was extremely small in comparison to the yield obtained after incubation with sucrose, so that there could be no doubt that by far the principal part of the polysaccharide found in the incubated test mixtures represented material synthesized through the action of the sterile extract.

The reaction with sucrose was recognizable not only by serological test but also by simple observation of the development of opalescence and by chemical tests for alcohol-precipitable material and for reducing sugars. The set of phenomena which always characterized the action of the sterile extract is illustrated by the data of the following experiment.

A series of mixtures consisting of one part of sterile extract plus one part of sterile (filtered) 10 per cent sucrose<sup>2</sup> solution in 0.2 molar acetate buffer pH 5.6 was prepared in a series of tubes, for controls similar mixtures with heat-inactivated (30

<sup>2</sup> The sucrose used throughout the investigation was a sample of beet sugar known by previous test to be free from material reactive with the antisera (leuconostoc and Types 2, 20, and 12 pneumococci) with which the leuconostoc dextrans are reactive. It was used instead of reagent sucrose because the latter usually contains significant amounts of material reactive with leuconostoc or the related pneumococcus antisera (9, 10). The use for substrate of sucrose free of polysaccharide which is either identical or closely related to the polysaccharide product of the action of the extract seemed important for theoretical reasons, particularly because of the possible stimulatory influence of the presence of small amounts of the final product.

minutes at 55°C.) extract were included the incubation was at 23°C. At the time intervals listed in Table I the mixtures were observed for opalescence and one tube of each series was used for tests for alcohol precipitable material serological reactivity, and reducing sugar (8). The alcohol precipitated material was sedimented by centrifugation and redissolved in salt solution equivalent to the original volume of the sample, this solution was observed for opalescence, tested for serological reactivity and for amount of reducing sugar before and after acid hydrolysis for the hydrolysis the solution was heated with 1.0 N sulfuric acid for 6 hours in a sealed tube immersed in boiling water. The serological reactivity was determined by test against 1:15 dilutions of a Type 2 antipneumococcus rabbit serum the pre-

TABLE I  
*Action of the Sterile Extract upon Sucrose*

Test mixture	Incubation period	Properties of test mixtures				Properties of solutions of the alcohol precipitate		
		Opalescence	Precipitability with 1.5 volumes of alcohol*	Serological reactivity†	Reducing sugars (without hydrolysis)	Opalescence	Serological reactivity‡	Reducing sugars after acid hydrolysis§
	hrs.				mg./cc.			mg./cc.
Unheated extract plus sucrose	0	0	±	10	0.07	0	10	0.04
	6	+	++	200	0.4	+	200	0.3
	12	+±	+++	400	1.0	++	400	0.9
	24	++	++++	1000	2.4	++	1000	2.0
	48	+++	++++	1500	4.0	+++	1500	3.9
	96	++++	++++	3000	7.8	++++	4000	6.6
	192	++++	++++	7000	10.8	++++	7000	9.0
Heated extract plus sucrose	96	0	±	10	0.08	0	10	0.02
	192	0	±	10	0.09	0	10	0.02

\* Test mixture diluted 1:5 in 10 per cent sodium acetate before addition of the alcohol.

† Dilution which gave precipitation with Type 2 antipneumococcus serum.

§ Only traces (0.02 to 0.03 mg. per 1 cc.) of reducing sugars before hydrolysis.

capitation reaction was observed after 1½ hours incubation at 37°C. In the summary of the results presented in Table I the reducing sugars are calculated as glucose.

It is evident (Table I) that the development of the different phenomena (opalescence, serological reactivity, material precipitable with 1.5 volumes of

of the enzymatic action. From the practical standpoint of possible confusion in the final serological tests the presence of reactive material in the sucrose substrate would be important only in the serological test of relatively low dilutions of enzyme-substrate mixtures. Since all the experiments reported were done with sucrose derived from beet it should be noted that a sufficient number of well controlled experiments were made with cane sugar as substrate to prove that the sterile extracts can also form the reactive polysaccharide from sucrose of that origin.

alcohol, and free reducing sugar) proceeded at an orderly rate when the unheated extract was incubated with sucrose, and that none of those phenomena occurred in the control mixture of sucrose plus heated extract

The alcohol-precipitable material can be accepted as the product responsible for both the opalescence and the serological reactivity of the test mixture, the free reducing sugar represents another product of the action of the bacterial extract upon sucrose. It is important that throughout the course of the reaction the amount of free reducing sugar which had accumulated in the test mixtures was about the same as the amount of reducing sugar obtained by acid hydrolysis of the alcohol-precipitated material. This approximate agreement suggests that the action of the extract consists of the conversion of  $x$  molecules of sucrose into a polymer of  $x$  glucose anhydride units plus  $x$  molecules of fructose. Although that mechanism is not proved, data to be presented in Table II show that the polysaccharide is a dextran and other experiments which we have made indicate that the free reducing sugar is fructose.<sup>3</sup>

#### *Chemical and Serological Properties of the Purified Polysaccharide Product*

The facts (Table I) that the serological reactivity which developed in the sucrose-extract mixtures was resident in the alcohol-precipitable fraction and

<sup>3</sup> The supernatant fluids of extract-sucrose mixtures from which the dextran had been removed by alcohol precipitation, yielded large amounts of glucosazone (identified by crystalline appearance and by melting point) when heated with phenylhydrazine and sodium acetate. That the material from which the glucosazone was derived was a product of the action of the extract upon sucrose was proved by the lack of formation of glucosazone when the supernatant fluids of mixtures of heat-inactivated extract plus sucrose were subjected to similar treatment. These results indicated that the reducing substance was either glucose, mannose, or fructose.

More specific evidence was obtained by experiments utilizing the procedure of Ellert (11) (the low concentration of the reducing substance in our test mixtures prevented the use of the methylphenylhydrazine method and the presence of sucrose in the mixtures prevented the use of the usual color tests for fructose). The method consists simply of the addition of two or three drops of 4 N NaOH and a small piece of solid NaOH to two or three drops of the test solution on a porcelain plate. If fructose is present a pink to blood red color develops which is not given by other common carbohydrates. When this procedure was applied to mixtures of sucrose plus active extract which contained from 0.3 to 1.0 per cent of free reducing sugar, they always gave the pink to red color. Control tests with 0.3 to 1.0 per cent solutions of reagent fructose gave pink to red colors of intensities comparable to those shown by the sucrose-extract mixtures of corresponding reducing sugar content. Similar tests made upon mixtures of heat-inactivated extract plus sucrose, upon solutions containing 1 and 10 per cent sucrose, glucose, galactose, xylose, arabinose, maltose, or lactose, gave either a yellow color or no color, the purified *Leuconostoc* dextran (1.0 per cent) gave no color. Thus, although the reducing sugar formed by the action of the extract upon sucrose was not actually isolated and identified there is considerable reason to believe that it is fructose.

that this fraction yielded abundant amounts of reducing sugar upon acid hydrolysis indicated that the product responsible for the serological reactivity was a polysaccharide. It seemed important to obtain purified preparations of this product in sufficient amount for an adequate comparison of its chemical and serological properties with those of the dextran polysaccharide which is formed in sucrose broth cultures of the leuconostoc bacteria from which the extracts had been derived. A preparation of dextran from sucrose broth cultures was available from another investigation (6) and for the present experiments two lots of polysaccharide were prepared utilizing sterile extracts made at times several months apart.

For lot 1 the test mixture was 20 cc. of bacterial extract plus 380 cc. of sterile 10 per cent sucrose in 0.1 M acetate buffer solution pH 5.6 for lot 2 the mixture was 300 cc. of the buffered sucrose solution plus 15 cc. of the bacterial extract. The first lot was incubated 9 days and the second lot 7 days at 23°C. Control mixtures (heat inactivated extract plus sucrose and unheated extract plus buffer) were also prepared and incubated for the same periods. At the end of the incubation period the test mixtures were opalescent and apparently contained adequate amounts of the polysaccharide product; the control mixtures remained clear and furthermore gave no precipitate upon addition of 10 per cent sodium acetate and 1.5 volumes of alcohol.

The polysaccharide material from lots 1 and 2 was isolated and purified by the procedure described for preparation of the dextran from broth cultures (6). After addition of 10 per cent sodium acetate, 1.5 volumes of alcohol were added to the extract-substrate mixtures; the abundant gummy precipitate was dissolved in a volume of water equal to that of the original mixture and was then reprecipitated in the presence of acetate by the addition of 1.25 volumes of alcohol. This precipitate was redissolved in 300 cc. of water and after the addition of 10 gm. of sodium acetate and 5 cc. of glacial acetic acid was shaken mechanically with chloroform to remove any traces of protein (5, 12). The chloroform-protein emulsion layer was only small in amount after the first treatment and was entirely absent after the third treatment. The protein-free material was then twice precipitated by 1.25 volumes of alcohol in the presence of acetate; the final precipitate was ground under absolute alcohol and dried in vacuum over  $\text{CaCl}_2$  at room temperature. The yield was 0.70 gm. of the purified polysaccharide from lot 1 and 0.45 gm. from lot 2, which represents, respectively, 175 and 143 mg. per 100 cc. of the extract-sucrose mixtures. It is noteworthy that the yields obtained through the action of these sterile extracts is greater than the yields of polysaccharide ordinarily obtained from whole cultures of pneumococci and many other bacteria.

Both of the purified preparations were analyzed chemically and tested serologically. The specific optical rotation (sodium D line at 24°C.) of the original products was determined with 0.4 per cent solutions. For determining the properties after hydrolysis 0.2 gm. of each product was heated for 6 hours with 1.0 N sulfuric acid in a sealed tube immersed in boiling water in addition to the analyses for reducing sugars (8) and for optical rotation, the hydrolysate was treated with phenylhydrazine and oxidized with nitric acid (13) in order to get more specific information on the nature of the reducing sugar in the hydrolyzed material.

periments It was known from a previous study (6) that absorption with leuconostoc bacteria would remove the capacity to react with the dextran of culture source from all of the antisera listed in Table III provided the leuconostoc used for the absorption had been grown in sucrose broth, whereas absorption with pneumococci (2, 20, or 12) would fail to remove the dextran-reacting capacity from any of the antisera other than the homologous anti-pneumococcus type When these experiments were repeated with dextran of extract origin together with dextran of culture origin, the two behaved exactly alike, that is, the absorption treatment which removed the antibodies reactive with one always removed the antibodies reactive with the other, and the treatments which failed to remove the antibodies reactive with one always failed to remove the antibodies reactive with the other<sup>5</sup>

In spite of the striking similarity in the serological properties from a qualitative standpoint, it should be noted that one lot (No 1) of dextran of extract source did not react in as high dilution as did the dextran isolated from the culture However, this difference seems relatively unimportant because both lots (Nos 1 and 2) of extract origin reacted in sufficiently high dilution (1 500,000 and 1 1,000,000) to prove the fundamental point that polysaccharides produced in the absence of living cells can approach if not equal the quantitative serological capacity of the polysaccharides produced in the usual sucrose broth cultures of the bacteria

#### *Influence of pH upon the Action of the Extract*

The substrate-extract test mixtures in all the previously described experiments were maintained at about pH 5.6 by the use of acetate buffer That routine was adopted at the beginning of the investigation because of an early observation that the extracts acted upon sucrose more rapidly at that pH than at pH 7.0 In order to get more systematic information on the influence of pH the following experiment was made

A series of mixtures consisting of one part of extract, one part of 20 per cent sucrose, and two parts buffer solution were prepared, which gave test systems ranging from

<sup>5</sup> In addition to furnishing evidence on the likeness of the dextrans from the two sources, these experiments illustrate an interesting difference between Type 2 pneumococci and leuconostoc bacteria in respect to the influence of growth in sucrose broth upon the antigenic properties of the two sorts of bacteria (6, 15) That is, the capacity to evoke antibodies reactive with the leuconostoc dextran or to remove the anti-dextran antibodies from a reactive serum, is possessed by leuconostoc bacteria which have been grown in sucrose broth but not by leuconostoc bacteria which have been grown in glucose broth, whereas Type 2 pneumococci which have been grown in plain or in glucose broth can not only evoke the dextran antibodies but also can absorb them from antisera produced by immunization with Type 2 pneumococci which have been grown either in sucrose or non-sucrose broth

pH 3.0-9.0, citrate buffer was used for the pH 3.0, acetate for the pH 4.0, 5.0, and 5.5, phosphate for the pH 6.0, 7.0, and 8.0, and borate for the pH 9.0 mixture. The pH which was tested at the beginning and again at the times of each serological determination, remained approximately constant in all the mixtures except the pH 9.0 borate which dropped to pH 8.5 early in the experiment. The test mixtures were incubated at 23°C. In order to measure the formation of serologically reactive material samples were removed from each mixture at the times shown in Fig. 1 and tested in a series of dilutions against a 1:15 dilution of Type 2 antipneumococcus serum; the samples were adjusted to about pH 7.0 by diluting them 1:10 in 0.1 M phosphate solution before using them in the serological tests.

It is evident (Fig. 1) that the extract formed significant amounts of the serologically reactive material over the relatively wide zone of pH 4.0-8.0 but that

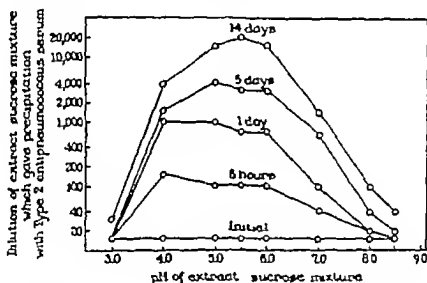


FIG. 1. The formation of serologically reactive material in extract-sucrose mixtures of different pH.

its action was more rapid between pH 4.0 and 6.0 than at pH 7.0 or above. The final yield of the reactive product was greater in the zone of pH 5.0-6.0 than in more acid or more alkaline systems. Four other lots of extract which had been prepared at different times over a period of 9 months were also compared in test systems of pH 5.5 and 8.2. All of these extracts produced at least 100 times more reactive material after 5 days incubation at 23°C in the pH 5.5 mixture than in the pH 8.2 mixture, which indicates that the results in Fig. 1 are representative of extracts prepared from this strain of *Leuconostoc*.

#### *Influence of Temperature of Incubation*

The routine temperature of incubation of the substrate-extract test mixtures was 23°C. The enzyme, however, had the capacity of forming the serologically reactive material over a range of at least 3-37°C. In experiments made with 5 different lots of extract, evidence was obtained that considerable

inactivation of the enzyme occurs in mixtures incubated at 37°C. For example, the amount of serologically reactive material formed at 37°C was about the same as that formed at 23°C during the first 5 hours of incubation, but after periods of 3 days the mixtures incubated at 23°C invariably contained at least 5 times as much of the reactive product as did the corresponding mixtures incubated at 37°C. This apparent slowing of the reaction at 37°C became even more apparent after 10 and 20 days by which time the mixtures incubated at the low temperature of 3°C contained about 5 times as much of the reactive product as that in the mixtures incubated at 37°C. The amount formed at 3°C never equalled that produced by the same extract at 23°C during the 20 day period of the experiment. However, the fact that 3°C was sufficient for a reasonably high degree of activity on the part of the *Leuconostoc* enzyme is of interest because at that temperature cultures of those bacteria will grow little if at all.

#### *Lability of the Active Agent*

The active agent of the extracts is heat-labile. Control mixtures of heated extract (30 minutes at 55°C) plus sucrose were included in each experiment throughout the investigation and in no instance was any reactive material formed. This routine heating treatment was evidently more than sufficient since 5 minutes exposure to either 50° or 55°C usually resulted in practically complete inactivation whether the extracts were heated in systems of pH 5.5 or pH 7.0.

Observations on the question of lability at 37°C were made with several lots of extract. The active agent in all of them was destroyed more rapidly when the exposure (in the absence of sucrose) was in systems of pH 7.0 than when in systems of pH 5.5. Individual extracts varied in the degree to which they showed this difference. With some the difference was great; for example, one extract lost at least 90 per cent of its original activity when it was exposed for 4 hours at pH 7.0 whereas only a slight loss in activity occurred when it was exposed for the same time at pH 5.5. Controls were included to show that the greater lability at 37°C on the part of extracts held at pH 7.0 was not due to any action of the phosphate which was used as buffer. The difference in the degree of lability at 37°C which occurred among the individual extracts suggests that some unrecognized impurity present in different concentrations in the various extracts may have participated in the destruction of the active principle of the extract. Experiments will be made to determine whether or not the inactivation at this comparatively low temperature represents an oxidative process.

#### *Active Extract from a Glucose Broth Culture*

Cultures of *Leuconostoc mesenteroides* produce abundant amounts of the reactive dextran when grown in sucrose medium but produce none of it when



grown in mediums in which glucose or other common carbohydrates are substituted for sucrose. The failure of the bacteria to produce the dextran in the latter mediums can reasonably be explained on the basis that these mediums lack the substrate (sucrose) required for the synthesis of the dextran. Nevertheless, it seemed of interest to determine whether or not the bacteria after repeated passage in a medium lacking sucrose would elaborate the enzyme involved in the dextran synthesis. For the investigation of that question the *leuconostoc* bacteria (which previously had always been grown in sucrose mediums) were transferred 9 successive times in glucose broth, and an extract was then prepared by exactly the same procedure as previously described.

This extract was found to possess the capacity to form the polysaccharide when added to sucrose, but its potency was low. For example, the extract derived from the glucose culture when used in a dilution of 1:2 produced about the same amount of polysaccharide as did 1:50 or 1:100 dilutions of the extracts derived from sucrose cultures. These results show that the *leuconostoc* bacteria can elaborate some amount of the enzyme involved in the dextran synthesis when grown in the absence of sucrose. However, the lower degree of reactivity of the extract derived from the glucose culture indicates that the presence of sucrose during the growth of the bacteria has a stimulatory influence upon the elaboration of the enzyme.

#### DISCUSSION

The experiments dealt with the production from sucrose of a serologically reactive polysaccharide of dextran nature by the action of sterile filtered extracts obtained from cultures of *Leuconostoc mesenteroides*. That other common carbohydrates do not yield the polysaccharide which is formed from sucrose was shown previously (1) and further information on that point will be given later. The active principle in the extracts was heat labile and presumably was an enzyme or combination of enzymes. From the method of preparation it can be assumed that the active principle was "exocellular" or free in the fluid of the cultures from which the extracts were obtained. However, although it was a less convenient method, active extracts were also obtained by grinding the bacterial cells which indicates that some of the active agent also occurs within or upon the surface of the cells.

In regard to chemical properties the polysaccharide formed by the sterile extract was similar to the polysaccharide produced in sucrose broth cultures, both could be classified as dextrans on the basis of their high positive optical rotation, high content of reducing sugars after hydrolysis and by evidence that glucose comprised at least the principal portion of the hydrolyzed products. In regard to serological properties the dextrans of extract and of culture source were strikingly similar not only in tests against *leuconostoc* antiserum but also in tests against Types 2, 20, and 12 antipneumococcus serums and in tests against a series of variously absorbed antisera. This agreement in the

antipneumococcus cross reactions and in the reactions against the absorbed serums represents evidence of a closer serological likeness between the dextrans of the two sources than would be furnished by tests against leuconostoc anti-serum alone

No intensive study of the mechanism of the action of the sterile extracts was made other than to show that the products are formed at a reasonably orderly rate and that the reaction, which occurs to some extent over the relatively wide zone of pH 4.0–8.0, is more rapid and gives a higher final yield in systems between pH 5.0 and 6.0 than at pH 7.0 or above. It is of interest to point out that the elaboration of the dextran by the active agent of leuconostoc origin has at least two points in common with the syntheses of glycogen and starch by enzymes of yeast, animal, and plant origins. That is, in regard to the final product of the reaction, the leuconostoc dextran like glycogen and starch is a complex polysaccharide composed apparently entirely of glucose units, and in regard to the substrate, the sucrose from which the dextran is derived, like the glucose-1-phosphate from which glycogen and starch are formed, is a glucoside. But the mechanism of formation of the dextran has not been studied enough to allow any closer comparison, for example the questions of whether or not phosphorus compounds participate and of whether or not the reaction is reversible have not been determined.

Although the experiments of this paper included extracts prepared from only one strain of *Leuconostoc mesenteroides*, the possession of a demonstrable polysaccharide-synthesizing enzyme is not peculiar to this strain. Sterile extracts which form serologically reactive polysaccharides similar to those produced in the corresponding bacterial cultures, have been prepared not only from 5 other strains of leuconostoc but also from group H streptococci, *Streptococcus salivarius*, and several non-spore-forming bacilli (presumably lactobacilli) isolated from plants. However, for the demonstration of the "enzymatic synthesis" of serologically reactive polysaccharides, all of these kinds of bacteria seem to have at least two advantages over the majority of microorganisms. First, the extraordinarily large amounts of the polysaccharide found in the whole cultures would indicate them to be a likely source from which to isolate a sufficient amount of enzyme or active agent to produce demonstrable amounts of the polysaccharide in the absence of the cells. Secondly, the formation of the polysaccharide by these bacteria can be referred to a definite constituent (sucrose or raffinose) of the medium. Of these two advantages the knowledge of the substrate is probably the more important, and indeed the other apparent advantage may depend entirely upon it. For example, in the case of leuconostoc and of the other kinds of bacteria from which we have prepared active extracts, the extraordinarily large amounts of polysaccharide are produced only when the medium contains relatively large amounts of the particular substance (sucrose and sometimes raffinose) from which the polysaccharide is elaborated, if none of that substance is available none of the polysaccharide

is produced. In the case of pneumococci and most other bacteria the actual substrates from which the specific polysaccharides are made are entirely unknown not only in regard to their chemical nature but also in regard to whether they represent original constituents of the medium or some intermediate products of bacterial metabolism. But in either event if it were possible to supply the appropriate substances in adequate amount the yield of specific polysaccharide might perhaps become as abundant as the yield of dextran in sucrose broth cultures of *Leuconostoc*.

#### SUMMARY

A serologically reactive polysaccharide of dextran nature was produced from sucrose by the action of some enzyme or similar heat labile agent contained in sterile filtered extracts derived from sucrose broth cultures of *Leuconostoc mesenteroides*. Rigorous controls were included to prove that this reaction occurred in the absence of microorganisms.

Purified preparations of the dextran formed by the sterile extracts were similar to the dextran elaborated in sucrose broth cultures of the bacteria in respect to both chemical and serological properties. The serological likeness was established not only by tests against *Leuconostoc* antiserums but also by cross reactions with antiserums of Types 2, 20, and 12 pneumococci and by tests against a series of variously absorbed antiserums.

#### BIBLIOGRAPHY

1. Hehre, E. J. *Science*, 1941 93, 237
2. Beijerinck, M. W., *K. Akad. Wetensch. Amsterdam Proc. Sect. Sc.*, 1910 12, 635
3. Harrison, F. C., Tarr, H. L. A., and Hibbert, H., *Canad. J. Research* 1930 3, 449
4. Dienes, L. *J. Infect. Dis.* 1935 57, 12, 22
5. Sevag, M. G. *Biochem. Z.*, 1934 273, 419
6. Sugg, J. Y. and Hehre, E. J. *J. Immunol.* 1942 43, 119
7. Neill, J. M., Sugg, J. Y., Hehre, E. J., and Jaffe, E. *Proc. Soc. Exp. Biol. and Med.*, 1941 47, 339
8. Hagedorn, H. C. and Jensen, B. N. *Biochem. Z.* 1923 135, 46
9. Neill, J. M., Hehre, E. J., Sugg, J. Y. and Jaffe, E. *J. Exp. Med.* 1939 70, 427
10. Neill, J. M., Sugg, J. Y., Hehre, E. J. and Jaffe, E. *Am. J. Hyg. Section B* 1941 34, 65
11. Ekkert, L., *Pharm. Zent.* 1928 69, 805
12. Heidelberger, M., Kendall, F. E. and Scherp, H. W. *J. Exp. Med.* 1936 64, 559
13. Van der Haar, A. W., *Anleitung zum Nachweis, zur Trennung und Bestimmung der Monosaccharide und Aldehydsäuren*. Berlin, Geb. Borntraeger 1920, 100
14. Fowler, F. L., Buckland, I. K., Brauns, F. and Hibbert, H. *Canad. J. Research Section B* 1937 15, 486. Peat, S., Schluchterer, E. and Stacey, M. *J. Chem. Soc.*, 1939 581. Hassid, W. Z., and Barker, H. A. *J. Biol. Chem.* 1940, 134, 163
15. Sugg, J. Y., Hehre, E. J. and Neill, J. M., *J. Bact.*, 1942, 43, 24.



## OBSERVATIONS ON THE CONDITIONS OF DIETARY HEPATIC INJURY (NECROSIS, CIRRHOSIS) IN RATS\*

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### PLATE 12

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It was reported in 1939 (2) that hepatic injury, mainly in the form of acute focal or diffuse necrosis combined with fat infiltration, occurred irregularly in young rats fed a diet devoid of vitamin B (casein 18 per cent, cane sugar 68, melted butter fat 8, cod liver oil 2, salt mixture 4) and supplemented with thiamine, riboflavin, and pyridoxine. In a group of more than 300 rats, 48 exhibited hepatic changes of the type described. In livers of 4 of the rats there was diffuse periportal fibrosis.

Admittedly, even when hepatic injury was observed under apparently identical experimental conditions, it was found that it "could not be produced at will and was not a regular occurrence." No proof for an infectious or toxic origin of the pathological changes in the liver could be found and the evidence favored, rather, a nutritional basis (2). In this connection it is particularly noteworthy that injury to the liver was never encountered in rats which, for from 3 to 6 months, had been fed a diet deficient in the vitamin B complex and supplemented with thiamine, riboflavin, and 0.5 gm. of yeast daily. Nor was hepatic injury found in investigations on riboflavin deficiency (3, 4) involving approximately 500 rats which were fed the same basal diet supplemented with thiamine and yeast extract in the form of Peters' eluate (5). As this hepatic disease was not prevented by the administration of thiamine, riboflavin, and pyridoxine, it was assumed (2) that the hypothetical factor which protected the liver must be one that was different from these components of the vitamin B complex.

The incidence of hepatic injury remained practically unchanged in later groups of at least 250 rats<sup>1</sup> fed a vitamin B free diet, with daily supplements of 20 micrograms of thiamine, 20 to 25 micrograms of riboflavin, and 2 mg. of choline per gm. of diet (or 10 mg. of choline daily as a separate supplement).

\* A preliminary report of this work has been made (1).

<sup>1</sup> In this number is included the series of 169 rats referred to in footnote 1 of an earlier report (6).

and with or without the further addition of pyridoxine. Injury to the liver was also observed in rats which had received pantothenic acid because manifestations of pantothenic acid deficiency had become apparent on a diet supplemented with the factors mentioned. If the rats treated with pantothenic acid, however, survived the first 4 weeks of medication with distinct gain in weight, they remained permanently free from hepatic injury.

Another group of 25 young rats, weighing between 30 and 35 gm., which had received from the start all the supplements in question (vitamin B<sub>1</sub>, riboflavin, pyridoxine, pantothenic acid, and choline), exhibited no specific hepatic changes even for as long as 8 months after the beginning of the experiment.

One common denominator emerged as a conceivable etiologic factor out of the multitude of these variable observations. This was the possibility of low food intake with, at the same time, a sufficient supply of several or all the known members of the vitamin B complex. Limitation of hepatic injury to rats suffering from or convalescing from deficiency of one or more members of the vitamin B complex is consistent with this assumption, as the intake of food is probably especially low and variable under these conditions. On the other hand, the fact that hepatic injury is lacking in rats whose fairly normal development is not interrupted by deficiency conditions also tallies well with this view. As a further logical step it could be assumed that the low food intake is associated with low casein supply and therefore, in natural consequence, with the so called lipotropic activity of casein.

As the amounts of food ingested were not determined, special investigations were needed in order to make such a tentative conclusion more plausible. In the experiments which are reported here, an attempt has been made to employ different rations that were low in protein and moderately or distinctly high in fat.

In the meantime Rich and Hamilton (7) have reported the occurrence of cirrhosis of the liver in rabbits maintained on a deficient diet and its prevention by yeast. The exact nature of the deficiency was not determined. Spellberg and Keeton (8) also observed cirrhosis of obscure dietary origin in one guinea pig and one rabbit. In this connection it should be borne in mind that herbivorous animals, especially rabbits, are not altogether satisfactory experimental subjects for the study of hepatic cirrhosis. "Reagents which produce the disease in them fail to have the same effect on dogs, and from the spontaneous cirrhosis which occurs they would seem to be peculiarly susceptible to the disease" (9).

The production of cirrhosis of the liver in 3 dogs and in 7 rats fed high fat diets has been reported by Chaikoff and Connor (10) and by Blumberg (11), respectively. These results, however, were correlated not to the phenomenon of the lipotropic activity of casein but rather to the fat infiltration of the liver.

### *Experimental Method*

Rats with an initial weight of 130 gm. or more, in groups of 10 or more, were fed seven different rations, the composition of which is summarized in Table I. In all

but a few groups the diets were supplemented, as a matter of daily routine, with 20 micrograms of thiamine 25 micrograms of riboflavin, 20 micrograms of pyridoxine, and 100 micrograms of calcium pantothenate.<sup>2</sup> The daily intake of food was not determined. In a few groups 0.5 gm of dried brewer's yeast (Anheuser Busch, Inc.) was substituted for the vitamin supplements, three times a week. The vitamin solutions and the yeast, as well as the other special supplements, were given separately, that is, they were not mixed with the diet.

The feeding period of all the different groups was extended to 150 days or, exceptionally, a few days longer. Pathological examination of rats that died before the termination of the experiments followed as soon after death as possible.

In the overwhelming majority of the animals the diagnosis was made only after macroscopic and microscopic examination of the liver. As stated in the previous report (2) in a few rats the excited, hyperactive behavior might hint the presence of disease of the liver. Visible jaundice (yellow ears, bile stained urine) was observed

TABLE I  
*Composition of the Diets*

Constituent	Diet 8 I	Diet L II	Diet L III	Diet L IV	Diet L V	Diet C I
Casein smaco	18	10	6	18	5	8
Lard		20	23	20	20	
Crisco						38
Melted butter fat	8					
Cane sugar	68	64	15	56	69	48
Corn starch			50			
Cod liver oil	2	2	2	2	2	2
Salt mixture (12)	4	4	4	4	4	4

even less frequently. In the rats in which cirrhosis was found at autopsy, greasy sparse, matted fur, and brown seborrheic adherent scales on the skin chiefly over the back were often observed in life. Clinical ascites was suspected in only one rat of all the groups under investigation. At autopsy, however ascites alone and in the presence of especially advanced cirrhosis, ascites with pericardial and pleural effusion were observed several times although still rarely. The effusion fluid was found to be frequently bloody. Hematemesis and consequent anemia were equally exceptional findings. In these rats the anemia was hypochromic; for instance, in rat 6473 the blood count was hemoglobin 45 per cent, red blood cells 3,990,000, white blood cells 6,900, polymorphonuclear cells 11 per cent, small mononuclear cells 85 per cent, large mononuclears 4 per cent.

The growth curve of rats suffering from hepatic injury (necrosis or cirrhosis) exhibited varying tendencies, although as a rule, at least in the last stages of the disease,

<sup>2</sup> Thiamine chloride, riboflavin, pyridoxine, and calcium pantothenate were obtained from Merck & Co., Inc., Rahway, New Jersey; purified casein, choline chloride, L-cystine, and tyrosine from the S. M. A. Corporation, Chagrin Falls, Ohio; and DL-methionine from both of these sources.

retardation and even suppression with final loss of weight seemed to prevail. In many animals, however, milder forms of cirrhosis were not incompatible with progressive gain in weight.

The investigations reported here have been carried out during the last 3 years on over 360<sup>3</sup> rats. These experiments are being continued with special emphasis placed on the problem whether or not cirrhosis of the liver once produced can be influenced therapeutically. Thus far the special dietary factors have been tested only for the purpose of determining interference with the development of the lesions.

### *Pathological Findings*

In the livers of the rats in the various groups that received different percentages of protein and different supplements there is a great variety of pathological changes. Fat infiltration in some degree is almost invariably present. Less frequent is parenchymatous or fatty degeneration with variable degrees of fat infiltration. The most significant changes are diffuse or focal necrosis, with or without accompanying hemorrhage, and variable degrees of cirrhosis. As a rule, the necrosis is recognizable in the gross but a considerable degree of cirrhosis may exist without being obvious in the gross. The necrosis is mainly central and midzonal, but frequently a variable number of entire or almost entire lobules is the seat of this change. In some livers large portions of a lobe are necrotic, but thrombosis, which might also account for such massive necrosis, was not observed. In Tables II to IV, under the heading "necrosis" are included those livers which showed only this change. Under the heading "cirrhosis," however, is included a variable remnant of necrosis. Almost invariably, enmeshed in the fibrous connective tissue of the cirrhotic livers, there is still recognizable, in some form, a large or small remnant of the previously necrotic parenchyma of the liver. This varies from definitely recognizable partly or completely necrotic cells to globules of variable size and shape, most of which have a light yellow or greenish-yellow color in paraffin sections stained with hematoxylin and eosin. In frozen sections stained with Sudan IV these globules are pink or red and are also peroxidase positive. The exact nature of these globules has not yet been determined. Treatment of frozen sections for as long as 18 hours with absolute alcohol, methyl alcohol, acetone, ether, petroleum ether, xylene, dioxane, or pyridine does not dissolve out the constituent which takes the stain with the usual Sudan IV (Herxheimer), naphthol Sudan IV (Goldmann), naphthol Sudan black (Lison),<sup>4</sup> and the globules remain in their original form. They are presumably necrotic protoplasmic remnants of the

<sup>3</sup> Not all this number are included in this report.

<sup>4</sup> The Sudan black method of Lison, modified by Miss Ethel Lieb, technician at the Institute of Pathology.



original hepatic cells in which lipoidal material is probably in some form of intimate combination with the protein which interferes with its removal by lipid solvents. The globules, although undoubtedly of cellular origin but not present within cells, give a positive reaction for oxydase (alpha naphthol crystal violet method of Loele). Enmeshed also in the fibrous connective tissue are single cells or small islands of regenerating hepatic cells. These exhibit variation in size of nuclei, some large deeply basophilic nuclei and frequent mitoses. In the fibrous connective tissue of an occasional liver there is some golden yellow pigment, either within the cytoplasm of large mononuclear cells or in the form of granules of amorphous extracellular deposits. Most of this pigment gives the reaction for iron and is probably hemosiderin.

The gross and microscopic pictures of diffuse necrosis of the liver, with or without hemorrhage, have been described in detail and illustrated in a previous paper (1). The changes in these livers are exactly similar and resemble human acute or subacute diffuse necrosis of the liver.

Livers with cirrhosis often present in the gross a rough, nodular surface and, in severe cases, a typical "hobnail" appearance (Fig 1), but not infrequently the surface of the liver is relatively smooth and gives no indication of the degree of fibrosis.

Although the necrosis is usually central and midzonal, yet the cirrhosis is mostly periportal. However, the alteration of the natural architecture is usually so great that central veins are frequently not easily recognizable. The bands of connective tissue are usually very wide and frequently include more than one lobule (Fig 2). The probability is great that the diffuse fibrosis that occurs is a combination of condensation fibrosis as well as a definite increase of periportal connective tissue replacing the degenerated and necrotic parenchyma, but exactly how the fibrosis frequently becomes periportal is not yet quite clear. What is clear is that the necrosis evidently precedes the development of the cirrhosis. In this series of animals the multiplication of bile ducts has not been frequent or striking, but in an occasional liver this change has been definite. Although the precirrhotic changes are more like those of so called "toxic cirrhosis" or the precirrhotic stage of so called "acute yellow atrophy," yet the final picture is more like that of Laënnec's cirrhosis of both the multilobular and monolobular varieties. There is no exact correlation between the degree of fat infiltration and the degree of cirrhosis in the livers.

The kidneys of all rats were not examined, but in those that showed the most severe injury to the liver diffuse necrotizing nephrosis is frequent. The pathological changes in these kidneys differ somewhat from those previously reported (6) in much younger rats fed a choline deficient diet, in which the process was more severe. In these animals the change amounts to diffuse cortical hemorrhagic necrosis, and resembles human bilateral symmetrical cortical necrosis, but in the present series the change is best described as a necrotizing nephrosis.

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<sup>3</sup> Not all this number are included in this report.

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changes, whereas cirrhotic changes, when present, were of a very mild degree and even then were combined with necrosis. Necrosis alone was observed in the livers of 6 of the 17 rats and necrosis with beginning cirrhosis in 2 animals, the incidence, therefore, was still almost 50 per cent as compared with 75 per cent in the control group which received no choline.

In view of the known antagonistic effect of cystine on choline, as well as on casein, in experiments dealing with the lipotropic activity of casein (13), the influence of adding cystine to the diet on the production of hepatic injury was studied in another group of rats (Table II). Daily supplements of 100 mg of *L*-cystine were given to 11 rats. In the livers of all these animals signs of more or less severe cirrhosis were seen in the gross specimen and on microscopic examination. Thus it has been proved that cystine is a very potent factor in the accentuation of cirrhosis of the liver in rats.

To another series of 15 rats supplements of 50 mg of *L*-cystine were given daily. Pathological changes of the liver, mainly cirrhosis, were manifested by 14 of these rats. Acute diffuse cortical necrosis of the kidneys (6) was found in 4 of these animals.

Cirrhosis of the liver was observed in 3 of 4 rats fed a daily special supplement of 25 mg of *L*-cystine for 150 days. The liver of 1 rat which received only 12.5 mg of *L*-cystine daily for this period showed slight cirrhosis.

In conclusion, *L*-cystine appears to exert a definitely injurious effect on the livers of rats maintained on a diet low in casein, high in fat and low in choline. With larger doses of *L*-cystine the hepatic injury seemed to become more accentuated.

The effect of *L*-cystine on the liver was neutralized to a large extent by the daily addition of 10 and 20 mg of choline to diet L II (Table II). Only 4 of the 19 rats in this group exhibited necrotic changes and all 19 remained free from cirrhosis even up to 150 days of the experiment. It is noteworthy that the 4 rats with necrosis of the liver died before the 120th day of the experiment. Cortical necrosis of the kidneys did not occur in this series of animals.

A daily special supplement of 0.5 gm. of yeast neutralized the effect of 50 mg of *L*-cystine as well as that of the modified basal diet L II (Table II). The liver of only 1 rat of the 5 rats fed the special supplement exhibited slight cirrhosis during the 150 days of the experiment. Excellent growth and completely normal livers were observed in another 5 rats fed daily a combination of 50 mg. of *L*-cystine, 0.5 gm. of yeast, and 10 mg of choline as a special supplement (Table II).

The preventive effect of a supplement of yeast alone on dietary hepatic injury produced by diet L II became apparent even when a low dose of yeast (0.5 gm.) was given three times a week instead of daily (Table II) of a group of 14 rats maintained on the modified basal regime hepatic injury was manifested in only 2. When a daily special supplement of 12.5 mg of *L*-cystine, in addition to 0.5 gm. of yeast three times a week, was fed to 6 rats evidence of cirrhosis was found in the livers of only 2 rats and of necrosis in 1 rat. The further addition of 10 mg of choline to the regime of 5 rats prevented the appearance of pathological changes in the liver.

A daily special supplement of 20 mg of *DL*-methionine left the incidence of hepatic injury practically unaltered in a group of 6 rats but slightly allayed its severity (Table II). In contrast, special daily supplement of 40 mg of *DL*-methionine had the same prophylactic effect that was produced by cystine plus choline. It is especially interesting that the combined administration of 50 (or 25) mg of *L*-cystine and 20 mg of

## EXPERIMENTAL OBSERVATIONS

*Diet L II*—Twenty rats were put on diet L II in which the casein ratio was reduced from the 18 per cent generally used in investigations on the vitamin B complex (2) to 10 per cent, and 20 per cent of lard was substituted for the usual 8 per cent of

TABLE II  
*Results of Feeding 184 Rats Diet L II\**

Special supplements						Total No of rats treated	No of rats with no hepatic injury	Hepatic injury present			
L-Cytatine daily	Choline daily	dl Me- thio- nine daily	Liver extract daily	Yeast daily	Yeast 3 times a wk			No of rats	Necro- sis	Cir- rhosis	Necro- sis and cirrhosis
mg	mg	mg	gm	gm	gm						
—	—	—	—	—	—	20	5	15	2	9	4
—	20	—	—	—	—	17	9	8	6	—	2
—	—	20	—	—	—	6	1	5	1	1	3
—	—	40	—	—	—	8	8	—	—	—	—
—	—	—	0.2	—	—	9	3	6	6	—	—
—	20	—	0.2	—	—	6	2	4	4	—	—
—	—	—	—	—	0.5	14	12	2	2†	—	—
100	—	—	—	—	—	11	—	11	—	11	—
50	—	—	—	—	—	15	1	14	3	8	3
25	—	—	—	—	—	4	1	3	—	3	—
12.5	—	—	—	—	—	1	—	1	—	1†	—
50	20	—	—	—	—	8	6	2	2†	—	—
25	10	—	—	—	—	11	9	2	2	—	—
50	—	20	—	—	—	5	5	—	—	—	—
25	—	20	—	—	—	11	9	2	2†	—	—
25	10	40	—	—	—	6	6	—	—	—	—
50	—	—	0.2	—	—	11	10	1	—	1†	—
50	—	—	—	0.5	—	5	4	1	—	1	—
50	10	—	—	0.5	—	5	5	—	—	—	—
12.5	—	—	—	—	0.5	6	4	2	—	1	1
12.5	10	—	—	—	0.5	5	5	—	—	—	—

\* All animals except those receiving 0.5 gm of yeast three times weekly were fed diet L II routinely supplemented daily with 20 micrograms of thiamine, 25 micrograms of riboflavin, 20 micrograms of pyridoxine, and 100 micrograms of calcium pantothenate. The rats in the group receiving 0.5 gm of yeast three times weekly were not fed any further vitamin supplements

† Only mild changes were observed

butter (Table I) To this modified basal diet the routine daily supplements of B complex factors were added, as described. In the group of 20 rats hepatic injury became an almost regular complication (Table II) Necrosis without cirrhosis was observed in 2 rats, with cirrhosis in 4 rats, and cirrhosis without necrosis in 9 rats that died between the 92nd and the 140th experimental days or were killed on the 150th day

Addition of 20 mg of choline daily reduced the incidence of hepatic injury (Table II) which, in this series of 17 animals, manifested itself almost exclusively by necrotic

changes, whereas cirrhotic changes, when present, were of a very mild degree and even then were combined with necrosis. Necrosis alone was observed in the livers of 6 of the 17 rats and necrosis with beginning cirrhosis in 2 animals, the incidence, therefore, was still almost 50 per cent as compared with 75 per cent in the control group which received no choline.

In view of the known antagonistic effect of cystine on choline, as well as on casein, in experiments dealing with the lipotropic activity of casein (13), the influence of adding cystine to the diet on the production of hepatic injury was studied in another group of rats (Table II). Daily supplements of 100 mg of *l*-cystine were given to 11 rats. In the livers of all these animals signs of more or less severe cirrhosis were seen in the gross specimen and on microscopic examination. Thus it has been proved that cystine is a very potent factor in the accentuation of cirrhosis of the liver in rats.

To another series of 15 rats supplements of 50 mg of *l*-cystine were given daily. Pathological changes of the liver mainly cirrhosis, were manifested by 14 of these rats. Acute diffuse cortical necrosis of the kidneys (6) was found in 4 of these animals.

Cirrhosis of the liver was observed in 3 of 4 rats fed a daily special supplement of 25 mg of *l*-cystine for 150 days. The liver of 1 rat which received only 12.5 mg of *l*-cystine daily for this period showed slight cirrhosis.

In conclusion, *l*-cystine appears to exert a definitely injurious effect on the livers of rats maintained on a diet low in casein, high in fat and low in choline. With larger doses of *l*-cystine the hepatic injury seemed to become more accentuated.

The effect of *l*-cystine on the liver was neutralized to a large extent by the daily addition of 10 and 20 mg of choline to diet L II (Table II). Only 4 of the 19 rats in this group exhibited necrotic changes and all 19 remained free from cirrhosis even up to 150 days of the experiment. It is noteworthy that the 4 rats with necrosis of the liver died before the 120th day of the experiment. Cortical necrosis of the kidneys did not occur in this series of animals.

A daily special supplement of 0.5 gm. of yeast neutralized the effect of 50 mg of *l*-cystine as well as that of the modified basal diet L II (Table II). The liver of only 1 rat of the 5 rats fed the special supplement exhibited slight cirrhosis during the 150 days of the experiment. Excellent growth and completely normal livers were observed in another 5 rats fed daily a combination of 50 mg of *l*-cystine, 0.5 gm. of yeast, and 10 mg of choline as a special supplement (Table II).

The preventive effect of a supplement of yeast alone on dietary hepatic injury produced by diet L II became apparent even when a low dose of yeast (0.5 gm.) was given three times a week instead of daily (Table II) of a group of 14 rats maintained on the modified basal regime hepatic injury was manifested in only 2. When a daily special supplement of 12.5 mg of *l*-cystine, in addition to 0.5 gm. of yeast three times a week, was fed to 6 rats, evidence of cirrhosis was found in the livers of only 2 rats and of necrosis in 1 rat. The further addition of 10 mg of choline to the regime of 5 rats prevented the appearance of pathological changes in the liver.

A daily special supplement of 20 mg. of *dl*-methionine left the incidence of hepatic injury practically unaltered in a group of 6 rats but slightly allayed its severity (Table II). In contrast, special daily supplement of 40 mg of *dl*-methionine had the same prophylactic effect that was produced by cystine plus choline. It is especially interesting that the combined administration of 50 (or 25) mg of *l*-cystine and 20 mg of

*dl*-methionine daily proved to be beneficial to the liver, although when these supplements were given separately *l*-cystine was injurious and 20 mg of *dl*-methionine was practically without effect. The effect of *dl*-methionine given in combination with *l*-cystine is similar to that produced by the simultaneous administration of *l*-cystine and choline.

A liver concentrate,<sup>5</sup> which represented the fraction of an aqueous liver extract soluble in 95 per cent alcohol, has been tested as a special supplement to diet L II (Table II). This concentrate was considered by Woolley (14) to be a good source of members of the vitamin B<sub>2</sub> complex other than riboflavin, pyridoxine, and pantothenic acid, as they are needed by the rat. Administration of a daily dose of 0.2 gm of this concentrate, alone to 9 rats or together with 20 mg of choline to 6 rats, proved to be completely ineffective in preventing hepatic injury. From the additional result that it had a neutralizing effect on *l*-cystine given in doses of 50 mg daily to 11 rats, it could be concluded that in this combination the liver extract acts through its content of choline (or a choline-like substance). Thus these experiments with liver extract furnish new indirect evidence of the importance of the combined administration of cystine plus choline in the dietary management of hepatic injury in rats.

*Diet S I*—If it is assumed that the pathogenesis of dietary necrosis and dietary cirrhosis of the liver is comparable to that of fatty metamorphosis of the liver, as shown by the results of experiments on the lipotropic activity of casein (13), an increase in the content of casein in the experimental diet should have a preventive effect on hepatic injury caused by *l*-cystine similar to that caused by the addition of choline or *dl*-methionine. In accordance with this expectation, a special supplement of 50 mg of *l*-cystine daily was given with diet S I, which had a casein content of 18 per cent (Table I), but failed to provoke the slightest pathological change in the livers of 11 rats, even though it was administered for 179 days. The diet was routinely supplemented daily with 20 micrograms of thiamine, 25 micrograms of riboflavin, 20 micrograms of pyridoxine, and 100 micrograms of calcium pantothenate.

*Diet L IV*—In order to show that it was not the low content of fat in diet S I which was responsible for the results obtained, a special diet (L IV) was devised with the same relative amount (20 per cent) of fat (lard) as in diet L II but with 18 per cent of casein as in diet S I. The routine vitamin B complex supplements were added (Table I). The results obtained with diet L IV were again unequivocal. The high intake of casein prevented the appearance of hepatic injury in spite of the simultaneously high intake of lard, regardless of whether no special supplement (10 rats) or a special daily supplement of 50 mg of *l*-cystine (11 rats) was added to the diet.

*Diet L III*—Decreasing the content of casein in the diet below 10 per cent met with some difficulties. Experiments with diet L V, with a casein content of 5 per cent (Table I), showed that it contained apparently too little protein to permit survival of the rats for a period long enough to allow hepatic injury to develop. Substitution of corn starch for part of the content of cane sugar and increasing the casein level from 5 to 6 per cent resulted in diet L III (Table I), a slight modification of the ration recommended for special purposes by White and Jackson (15). The experiments performed with diet L III are summarized in Table III. The results were essentially

<sup>5</sup> Kindly supplied by Dr David Klein of the Wilson Laboratories, Chicago

the same as those obtained when rats were fed diet L II, with the distinction that the addition of *l*-cystine in a dose as low as 12.5 mg. daily had a markedly aggravating effect on the incidence of hepatic injury in 6 of the 7 rats that received this dosage. In all 5 rats that received 25 mg. of *l*-cystine daily as a special supplement not only was severe cirrhosis manifested but in 4 of these animals acute necrotizing nephrosis

TABLE III  
*Results of Feeding 44 Rats Diet L III\**

Special supplement			Total No. of rats treated	No. of rats with no hepatic injury	Hepatic injury present			
<i>l</i> -Cystine daily	Choline daily	Yeast 3 times a wk.			No. of rats	Necrosis	Cirrhosis	Necrosis and cirrhosis
mg.	mg.	gm.						
—	—	—	13	3	10	5	4	1
25	—	—	5	—	5	—	5	—
12.5	—	—	7	1	6	—	6	—
25	10	—	6	4	2	2†	—	—
12.5	10	—	5	4	1	1†	—	—
—	—	0.5	8	8	—	—	—	—

\* For routine daily supplements see note\* Table II.

† Only mild changes were observed

TABLE IV  
*Results of Feeding 62 Rats Diet C I\**

Special supplement			Total No. of rats treated	No. of rats with no hepatic injury	Hepatic injury present			
<i>l</i> -Cystine daily	Choline daily	Yeast 3 times a wk.			No. of rats	Necrosis	Cirrhosis	Necrosis and cirrhosis
mg.	mg.	gm.						
—	—	—	12	2	10	1	8	1
25	—	—	11	1	10	1	9	—
25	10	—	10	7	3	—	3	—
—	—	0.5	9	7	2	—	2	—
25	—	0.5	10	5	5	—	5	—
25	10	0.5	10	10	—	—	—	—

\* For routine daily supplements see note\* Table II

was also observed. The beneficial effect of the combined administration of cystine plus choline, as well as of 0.5 gm. of yeast three times a week, could again be clearly demonstrated.

*Diet C I*—The most severe hepatic changes (necrosis, cirrhosis), often accompanied by ascites and pleural and pericardial effusion, were found in rats fed diet C I (Table I), which had a low content of casein (8 per cent) and high content of fat (crisco, 38 per cent). The increased intake of fat certainly aggravated the manifestation of hepatic injury (Table IV). The effects of the administration of *l*-cystine, on the one hand, and of *l*-cystine plus choline, on the other hand, were fully consistent with the

results characteristic of diets L II and L III. Acute necrotizing nephrosis was seen only in the group of rats that received the special supplement of *l*-cystine alone.

The results obtained with the use of diet C I, therefore, are a direct confirmation and corroboration of conclusions already firmly established.

#### DISCUSSION

The experiments reported here show conclusively that in the production of dietary hepatic injury (necrosis and cirrhosis, with or without ascites and pericardial and pleural effusion) the determining factors are known to be connected with the lipotropic action of casein (13). In short term experiments identical conditions produce fatty metamorphosis in the liver, whereas experiments of longer duration, up to 150 days, lead to necrosis or cirrhosis of the liver in rats.

At the same time, independently of these investigations and the preliminary publication (1) of their results, Webster (16) arrived at similar deductions. Results of experiments likewise independently conducted, which were published later by Blumberg and McCollum (17) as well as by Sebrell and his collaborators (18), are in essential agreement with those of the present and preliminary (1) series. Fat infiltration of the liver has been considered earlier by Connor (19) a prerequisite of cirrhosis, without correlating this assumption to the phenomenon of the lipotropic activity of casein and to its mechanism.

The lipotropic action of casein is generally (13) believed to be in direct proportion to its content of methionine and to the presence of choline in the diet, but it is reversely influenced by administration of *l*-cystine and supplements of fat, especially cholesterol. Identical conditions seem to regulate also the occurrence of cortical hemorrhagic necrosis of the kidneys as it is observed mainly in young rats (6, 20). A thorough review of the experimental data given here reflects mirror-like all the conditional factors in their relation to necrosis and cirrhosis of the liver. Thus, the prophylactic effect in rats of a high intake of casein or of adequate supplements of methionine and choline is noted, the latter mainly in combination with cystine. Striking is the fact that hepatic injury is caused by supplements of *l*-cystine alone and by a high fat ratio in the diet, which appears to operate here in the same way as in the mechanism of fat infiltration of the liver.

One minor discrepancy between the conclusions reached by Blumberg and McCollum (17) and those reported in this and the preliminary paper (1) refers to the rôle of choline in the prevention of hepatic injury. According to Blumberg and McCollum addition of choline to the diet (10 mg per gm of diet) resulted in normal livers, whereas in the studies reported here when choline (20 mg per day) was added as a separate supplement to a slightly different form of diet, low in protein and moderately high in fat, hepatic injury, especially in the form of necrosis, still occurred in about 50 per cent of the animals (Table II). It is noteworthy that choline, even when it is given in combination with liver extract (Table II), proved to be ineffective in the prevention of hepatic



injury In contrast, the combined administration of *l*-cystine and choline has been found to be very beneficial in all experiments of the present series. As a matter of fact, this latter result has been confirmed by Blumberg and McCollum (17) as well as by Daft, Sebrell, and Lillie (18)

That choline seems to act through the intermediation of *l*-cystine is also apparent from investigations (21) on hepatic injury in rats following ingestion of dimethylaminoazobenzene (butter yellow) It has been definitely established that choline or *l*-cystine, given separately, exerted no effect on the course of hepatic injury in rats maintained on diet L III when it was supplemented with butter yellow Administration of *l*-cystine plus choline, however, afforded definite protection.

The emphasis placed on the combined effect of cystine plus choline is at variance not only with the conclusion of Blumberg and McCollum (17) but also with that of Griffith (20) concerning the rôle of choline in the prevention of cortical necrosis of the kidney Furthermore, the importance of the combined administration of cystine plus choline has hardly been stressed in past work dealing with the phenomenon of the lipotropic activity of casein (13) The discrepancy is, of course, not a real one, in view of the fact that in all cases in which a beneficial effect was claimed from choline alone the diet used always contained cystine, even if only in small amounts

The combined effect of *l*-cystine plus choline is reminiscent of a similar phenomenon encountered lately in assays of the growth promoting activity of the essential amino acids which are linked with choline It has been shown by du Vigneaud and his collaborators (22) that homocystine would support growth on a methionine free diet only in the presence of choline or related substances and that methionine, on the other hand, can replace homocystine plus choline According to du Vigneaud and his coworkers, "The explanation presented as the most probable one for this observed relationship of choline to homocystine was that choline had acted as a donor of methyl groups for the synthesis of methionine from homocystine" (23) In these experiments on growth, cystine could not be substituted for homocystine It has recently been demonstrated, however, that methionine may be a precursor of choline in so far as the methyl groups are concerned (22) and that cystine is capable of stimulating growth only when methionine is present in suboptimal amounts (24)

Without being able to give a satisfactory explanation for all these reactions, particularly for the apparent lack of interchangeability of cystine and homocystine, we can say, however, that their relationship to the conditions that determine hepatic injury is evident In this connection it is significant that methionine in adequate doses prevents development of hepatic injury (Table II)\* just as well as it is prevented by *l*-cystine plus choline, and that suboptimal doses of methionine have the same detoxifying effect on cystine that choline

\* See also Daft, Sebrell, and Lillie (18)

has, methionine being, probably, a precursor of choline, as stated by du Vigneaud and his collaborators. It should be especially pointed out that, whereas with special supplements of liver extract alone (0.2 gm daily) to diet L II the average loss in weight in 150 days in 5 animals was found to be 36 gm and the average gain for 8 rats that received 50 mg of *L*-cystine daily for 150 days was 9 gm, an average gain of 99 gm occurred in a group of 11 rats that received liver extract plus *L*-cystine as special supplements. Similar differences were not noted in groups of rats fed special supplements of choline, *L*-cystine and choline plus *L*-cystine, respectively.

In conclusion, the impression is gained that the combined administration of choline plus *L*-cystine is necessary for the synthesis of a third substance (methionine?) which in its turn is concerned in the prevention of hepatic injury.

It is even more difficult to explain the hepatic injury caused by administration of *L*-cystine alone. Griffith (20) attributes it to some unspecific activation of the metabolism. This assumption it is not easy to reconcile with the fact that large toxic doses of *L*-cystine may, in a few days or weeks, produce necrosis of the liver (25) and, according to recent investigations, also the specific picture of Laennec's cirrhosis (26). It should be emphasized that in the present experiments and in those of Blumberg and McCollum, as well as of Daft, Sebrell, and Lilhe, the amounts of cystine administered as supplements were within the physiological limits of a normal diet. The identical response to toxic doses in short term experiments and to lower doses in investigations of longer duration speaks in favor of a specific effect.

The lipotropic action of casein is generally considered (13) to be completely determined by the interaction of cystine, methionine, and choline. Dissenting from this conception, Channon and his collaborators (27) seem to assume the presence of further, until now unidentified, and admittedly less important factors in casein. The experiments here reported have not taken into consideration the amount of cystine and choline administered sufficiently to render any conclusive answer to this problem. It should, however, be mentioned that, at least in the amounts chosen, supplements of *L*-cystine plus choline plus yeast or of *DL*-methionine in large doses were more effective in completely suppressing hepatic injury than was a supplement of *L*-cystine plus choline.

Application of the results of these experiments on rats to conditions in man is allowable only within the limitations of a conclusion *per analogiam*. Nevertheless, as circumstantial evidence, the unquestionable similarity of the etiological conditions that prevail in the most important form of human cirrhosis, namely, that observed in alcoholics, should be pointed out. Low intake of protein combined with insufficient supply of the vitamin B complex (including choline) is a prominent feature of the daily diet of persons addicted to alcohol and tallies with the leading conditions of dietary cirrhosis in rats. Thus, the assumption of a specific injurious effect of alcohol here becomes superfluous.

just as it does in pellagra or the beriberi of alcoholics. The recent claim of the beneficial effect of a "highly nutritious diet" supplemented with concentrates of the vitamin B complex (28) on cirrhosis in man is suggestive corroboration of the experiments presented here.

It is perhaps also permissible to call attention to the identical nutritional etiology of hemorrhagic cortical necrosis of the kidneys and of necrosis of the liver, and to the occurrence of both pathological lesions in pregnant women, hepatic injury (hemorrhagic necrosis) being often found in eclampsia.

From the point of view of general pathology it is of great interest that identical etiological conditions may lead, in rats, either to necrosis or to cirrhosis of the liver or to both.

The experiments reported here have been, thus far, exclusively of a prophylactic nature. Their scope needs to be extended to include therapeutic investigations. In a few animals in which hepatic injury was ascertained by biopsy, therapeutic administration of yeast or liver powder for a short time (up to 2 months) proved to be insufficient. These experiments are being continued on a larger scale and for prolonged periods.

#### SUMMARY

Experimental dietary hepatic injury (diffuse or focal necrosis and cirrhosis in rats, with or without ascites and pleural and pericardial effusion) is determined by the dietary factors instrumental also in the production of fat infiltration of the liver and thus opposed to the lipotropic activity of casein. Accordingly, rats maintained on a diet low in casein with a moderately high or high content of fat and without choline regularly exhibited hepatic injury after between 100 and 150 days. Supplements of *L*-cystine had an aggravating effect on the production of cirrhosis of the liver, whereas a supplement of choline alone reduced the severity and the incidence of hepatic injury, although not decisively. The combined administration of *L*-cystine plus choline or of *DL*-methionine in adequate doses, however, proved to be highly effective in preventing injury to the liver.

These conclusions have been corroborated by the use of different modifications of the basal diet.

Rats with dietary hepatic injury exhibit, in sequence, changes that vary from diffuse necrosis resembling human acute or subacute yellow atrophy, to advanced portal cirrhosis.

Diffuse necrotizing nephrosis was a frequent accompaniment of the hepatic injury. Cystine again proved to be a factor which aggravated this condition.

#### BIBLIOGRAPHY

1. György, P., and Goldblatt, H., *Proc. Soc. Exp. Biol. and Med.*, 1941 48, 492
2. György, P., and Goldblatt, H., *J. Exp. Med.* 1939 70, 185
3. György, P., *Biochem. J.*, 1935, 29, 741

- 4 Eckardt, R. E , and Johnson, L V , *Arch Ophth* , Chicago, 1939, **21**, 315
- 5 Kinnersley, H W , O'Brien, J R , Peters, R. A , and Reader, V , *Biochem J* , 1933, **27**, 225
- 6 György, P , and Goldblatt, H , *J Exp Med* , 1940, **72**, 1
- 7 Rich, A R., and Hamilton, J D , *Bull Johns Hopkins Hosp* , 1940, **66**, 185
- 8 Spellberg, M A , and Keeton, R. W , *Am J Med Sc* , 1940, **200**, 688
- 9 Davidson, J , *J Path and Bact* , 1925, **28**, 621
- 10 Chaikoff, I L , and Connor, C L , *Proc Soc Exp Biol and Med* , 1940, **43**, 638
- 11 Blumberg, H , *Pub Health Rep , U S P H S* , 1940, **55**, 531
- 12 Hubbell, R. B , Mendel, L B , and Wakeman, A. J , *J Nutrition* , 1937, **14**, 273
- 13 Cf Best, C H., and Ridout, J H., in Luck, J M , Annual review of biochemistry, Stanford University, Annual Reviews, Inc., 1939, **8**, 349
- 14 Woolley, D W , *Proc Soc Exp Biol and Med* , 1940, **43**, 352
- 15 White, A., and Jackson, R. W , *J Biol Chem* , 1935, **111**, 507
- 16 Webster, G , *J Clin Inv* , 1941, **20**, 440
- 17 Blumberg, H , and McCollum, E V , *Science* , 1941, **93**, 598
- 18 Lillie, R. D , Daft, F S , and Sebrell, W H., *Pub Health Rep , U S P H S* , 1941, **56**, 1255 Daft, F S , Sebrell, W H., and Lillie, R. D , *Proc Soc Exp Biol and Med* , 1941, **48**, 228
- 19 Connor, C L , *Am J Path* , 1938, **14**, 347, *J Am Med Assn* , 1939, **112**, 387
- 20 Griffith, W H , and Wade, N J , *Proc Soc Exp Biol and Med* , 1939, **41**, 188, 333, *J Biol Chem* , 1939, **131**, 567 Cf also Griffith, W H , *J Nutrition* , 1941, **22**, 239
- 21 György, P , Poling, E C , and Goldblatt, H , *Proc Soc Exp Biol and Med* , 1941, **47**, 41
- 22 du Vigneaud, V , Chandler, J P , Moyer, A W , and Keppel, D M , *J Biol Chem* , 1939, **131**, 57
- 23 du Vigneaud, V , Cohn, M , Chandler, J P , Schenck, J R , and Simmonds, S , *J Biol Chem* , 1941, **140**, 625
- 24 Womack, M , and Rose, W C , *J Biol Chem* , 1941, **141**, 375
- 25 Curtis, A. C , and Newburgh, L H , *Arch Int Med* , 1927, **39**, 828 Sullivan, M X., Hess, W C , and Sebrell, W H , *Pub Health Rep , U S P H S* , 1932, **47**, 75 Lillie, R D , *Pub Health Rep , U S P H S* , 1932, **47**, 83
- 26 Earle, D P , Jr , and Victor, J , *J Exp Med* , 1941, **73**, 161
- 27 Channon, H J , Manifold, M C , and Platt, A P , *Biochem J* , 1940, **34**, 866
- 28 Patek, A. J , Jr , and Post, J , *J Clin Inv* , 1941, **20**, 481

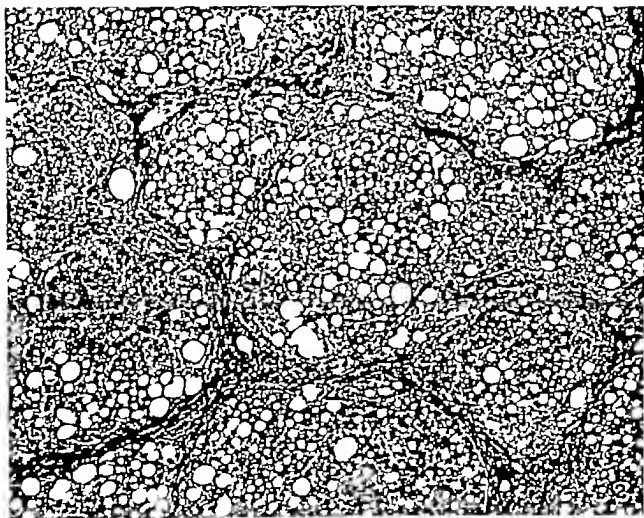
#### EXPLANATION OF PLATE 12

FIG 1 Cirrhotic liver of rat 6568 (Natural size )

FIG 2 Section of liver of rat 4628, showing moderate degree of cirrhosis and fat infiltration Masson trichrome stain  $\times 71$



1





## STUDIES ON THE ANTIBACTERIAL ACTION OF THE SULFONAMIDE DRUGS

### I. THE RELATION OF *p*-AMINOBENZOIC ACID TO THE MECHANISM OF BACTERIOSTASIS\*

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The mechanism whereby sulfanilamide and its derivatives prevent bacterial growth is not known. None of the various theories advanced (1-3) has been conclusively substantiated by direct experimental proof. The most important recent contribution to the problem has been that of Woods (4), who demonstrated that *p*-aminobenzoic acid "blocks" the bacteriostatic effect of sulfanilamide *in vitro*. Following the isolation by Stamp (5) and Green (6) of bacterial extracts which antagonize the action of sulfanilamide, Woods obtained from yeast a potent antisulfanilamide factor which appeared to have chemical properties similar to *p*-aminobenzoic acid but which could not be definitely identified as such. *p*-Aminobenzoic acid itself was found to annul the bacteriostatic effect of sulfanilamide, and Woods predicted that this simple organic acid would eventually be shown to be a metabolite essential for bacterial growth.<sup>1</sup> He also formulated the theory that sulfanilamide causes bacteriostasis by inhibiting specifically the enzymatic reaction involved in the utilization of *p*-aminobenzoic acid and attributed the inhibition of this reaction to the chemical similarity of the drug and the essential metabolite.

Important evidence supporting Woods' hypothesis was published in the same year by Rubbo and Gillespie (8). They reported the chemical isolation from

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<sup>1</sup> To prove a substance essential to bacterial metabolism it is necessary first to demonstrate that it is a growth factor for at least one bacterial species. A growth factor may be defined as an essential metabolite which cannot be synthesized by the bacterial cell and which, therefore, must be added to the culture medium to promote optimal growth. According to views first introduced by Fildes (7), substances known to be bacterial growth factors for one or more species of organism may be considered to be metabolites essential for the growth of many other bacteria and probably of bacteria in general.

yeast of the benzoyl derivative of *p*-aminobenzoic acid and stated in addition that *p*-aminobenzoic acid stimulated the growth of *Clostridium acetobutylicum* in a synthetic medium<sup>2</sup> Their observations led them to conclude that *p*-aminobenzoic acid is a bacterial growth factor and, therefore, an essential metabolite They pointed out, however, that in their experiments with *Cl. acetobutylicum* one molecule of *p*-aminobenzoic acid antagonized 23,000 molecules of sulfanilamide This tremendous disproportion between the antagonistic substances was interpreted as strong evidence against Wood's theory that the drug and the essential metabolite compete for the same receptor site on the organism

The data reported in the present paper concern the quantitative aspects of the antagonistic action of *p*-aminobenzoic acid and the more commonly used sulfonamide drugs A detailed study of the quantitative relationship between *p*-aminobenzoic acid and the bacteriostatic effect of sulfanilamide, sulapyridine, sulfathiazole, sulfadiazine, sulfaguanidine, and diaminodiphenylsulfone has been carried out under rigidly controlled conditions in an attempt to ascertain the manner in which *p*-aminobenzoic acid interacts with these different sulfonamide drugs It was hoped that knowledge of this interaction might lead to a clearer understanding of the mechanism of bacteriostasis and might possibly suggest an explanation for the marked differences in bacteriostatic potency exhibited by the various derivatives of sulfanilamide

### Materials and Methods

MacLeod (11) has demonstrated the widespread occurrence of sulfonamide inhibitors in ordinary bacteriological media, and has stressed the importance of using inhibitor-free media in studying the effect of sulfonamide drugs upon bacteria *in vitro* *Bacterium coli* was used in the present studies since it will grow luxuriantly in an inhibitor-free medium containing only asparagine as a source of nitrogen, glucose as a source of carbon, and inorganic salts The addition of *p*-aminobenzoic acid to the medium in concentrations corresponding to those used in the following experiments had no effect upon the growth of the organism as tested by repeated growth curves This fact is of primary importance since the antibacteriostatic effect of compounds which stimulate growth cannot be attributed to a specific action upon the drug, their effect may be due entirely to a non-specific stimulation of the growth of the organism<sup>3</sup>

<sup>2</sup>In attempting to confirm the important findings of Rubbo and Gillespie, both Lampen and Peterson (9) and Park and Wood (10) demonstrated independently that *p*-aminobenzoic acid will function as a growth factor for *Cl. acetobutylicum* only in the presence of biotin

<sup>3</sup>The non-specific effect of growth-stimulating substances is well illustrated by experiments reported in the next paper (12)



**Culture Medium**—The synthetic medium used was prepared in the following manner (13) 5 gm. of NaCl, 2 gm. of  $K_2HPO_4$ , 0.5 gm.  $MgSO_4$ , 2 gm. of ammonium citrate, and 3.5 gm. of asparagine were added to 1000 cc. of distilled water which had been brought to a boil. After being cooled the mixture was adjusted to a pH of 7.6 with sodium hydroxide (3 to 5 cc. of 2 normal NaOH), and was sterilized in the autoclave. 0.1 cc. of a 10 per cent solution of dextrose was added to the 10 cc. of basal medium in each tube before inoculation. The dextrose solution was sterilized by being heated to boiling for 5 minutes. Both the dextrose solution and the basal medium were stored in the ice box.

**Strain of *B. coli***—The strain of *B. coli communior* employed in the present experiments was obtained through the courtesy of Dr. Eleanor A. Bliss of the Department of Preventive Medicine of the Johns Hopkins Medical School. The organism was originally isolated from the urine of a patient with pyelitis. Daily subcultures were made in synthetic medium and these cultures were used as the source of organism in each experiment. The growth obtained in the synthetic medium was remarkably constant.

**Inoculum**—In all experiments the inoculum employed was 0.1 cc. of a 1:10,000 dilution of a 24-hour culture of *B. coli* in synthetic broth. The inoculum, as estimated by plate count, contained approximately 10,000 viable organisms.

**Preparation of Stock Solutions of Sulfonamide Drugs and *p*-Aminobenzoic Acid**—In 200 cc. lots of sterile basal medium sulfanilamide and sulfaguanidine were dissolved in concentrations of 0.01 molar, and sulfapyridine, sulfathiazole, sulfadiazine, and diaminodiphenylsulfone were prepared in 0.001 molar concentrations. The powdered drug was added in each case to boiling medium and the solution was allowed to cool slowly. The maximum concentration of each drug used was limited by its solubility in the basal medium. 0.001 molar *p*-aminobenzoic acid in synthetic broth was prepared by the same procedure.

**Method of Titration**—The antagonistic action of *p*-aminobenzoic acid to each sulfonamide drug was studied quantitatively by titrating the acid against the drug, the appearance of bacterial growth being used as an arbitrary end point. The desired concentrations of the antagonistic substances were attained by adding appropriate amounts of the stock solution of each to plain synthetic broth to make a final volume of 10 cc. 0.1 cc. of 10 per cent glucose was added to each tube just before it was inoculated. The tubes were examined at daily intervals for macroscopic evidence of bacterial growth and the final readings were made at the end of 5 days. All cultures were incubated at 37°C.

## RESULTS

Data from a typical titration experiment are recorded in Fig. 1. It will be noted that over a relatively wide range of sulfapyridine concentrations the minimum amount of *p*-aminobenzoic acid needed to prevent bacteriostasis at the end of 5 days was such that the ratio of *p*-aminobenzoic acid to sulfapyridine was approximately constant.<sup>4</sup> As the concentration of drug was decreased,

<sup>4</sup> A constant ratio of *p*-aminobenzoic acid to each sulfonamide drug was noted also at end points determined after 48, 72 and 96 hours as well as at the end of 5 days.

however, a point was finally reached where the ratio changed and rapidly approached zero. This sudden bend in the titration curve was obviously caused by the drug level's approach to the minimum concentration of sulfapyridine needed to cause bacteriostasis in the basal medium, and it in no way

	<i>Conc Sulfapyridine (moles)</i>							
	$9 \times 10^{-4}$ $5 \times 10^{-4}$ $2 \times 10^{-4}$ $1 \times 10^{-4}$ $5 \times 10^{-5}$ $2 \times 10^{-5}$ $1 \times 10^{-5}$							
<i>Conc p-Aminobenzoic Acid (moles)</i>	$2 \times 10^{-5}$	+	+	+	+	+	+	+
	$1 \times 10^{-5}$	+	+	+	+	+	+	+
	$5 \times 10^{-6}$		+	+	+	+	+	+
	$2 \times 10^{-6}$			+	+	+	+	+
	$1 \times 10^{-6}$				+	+	+	+
	$5 \times 10^{-7}$					+	+	+
	$2 \times 10^{-7}$						+	+
	$1 \times 10^{-7}$						+	+
	$5 \times 10^{-8}$							+
	$2 \times 10^{-8}$							+

FIG 1 Titration of *p*-aminobenzoic acid against sulfapyridine using bacterial growth as an arbitrary end point. + = visible growth of *B. coli* in 10 cc of a synthetic medium within 5 days of inoculation. Standard inoculum employed was 10,000 organisms. Cultures incubated at 37°C.

invalidates the linear relationship exhibited at higher concentrations. In the subsequent discussion of titration curves, therefore, only those points will be considered at which the drug level is well above the minimum bacteriostatic concentration.

The data summarized in Table I reveal a similar linear relationship between *p*-aminobenzoic acid and each of the sulfonamide compounds studied, the ratio of *p*-aminobenzoic acid to drug remaining approximately constant over

TABLE I

*Quantitative Study of the Antagonistic Action of p-Aminobenzoic Acid upon Various Sulfonamide Drugs*

Sulfonamide drug	Concentration (molar) Sulf. drug	Concentration (molar) P.a.b.a. needed to prevent bacteriostasis	Ratio: $\frac{\text{Molar conc. P.a.b.a.}}{\text{Molar conc. Sulf.}}$
Sulfanilamide	$9 \times 10^{-3}$	$6 \times 10^{-4}$	$6.7 \times 10^{-4}$
	$7 \times 10^{-3}$	$4 \times 10^{-4}$	$5.7 \times 10^{-4}$
	$5 \times 10^{-3}$	$3 \times 10^{-4}$	$6.0 \times 10^{-4}$
	$3 \times 10^{-3}$	$2 \times 10^{-4}$	$6.7 \times 10^{-4}$
	$2 \times 10^{-3}$	$1 \times 10^{-4}$	$5.0 \times 10^{-4}$
	$1 \times 10^{-3}$	$7 \times 10^{-7}$	$7.0 \times 10^{-4}$
Average ratio			$6.2 \times 10^{-4}$
Diaminodiphenyl sulfone	$9 \times 10^{-4}$	$6 \times 10^{-7}$	$6.7 \times 10^{-4}$
	$8 \times 10^{-4}$	$6 \times 10^{-7}$	$7.5 \times 10^{-4}$
	$7 \times 10^{-4}$	$5 \times 10^{-7}$	$7.1 \times 10^{-4}$
	$6 \times 10^{-4}$	$5 \times 10^{-7}$	$8.3 \times 10^{-4}$
	$5 \times 10^{-4}$	$3 \times 10^{-7}$	$6.0 \times 10^{-4}$
	$4 \times 10^{-4}$	$3 \times 10^{-7}$	$7.5 \times 10^{-4}$
Average ratio			$7.2 \times 10^{-4}$
Sulfaguanidine	$9 \times 10^{-3}$	$1 \times 10^{-4}$	$1.1 \times 10^{-3}$
	$5 \times 10^{-3}$	$5 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$2 \times 10^{-3}$	$2 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$1 \times 10^{-3}$	$1 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$5 \times 10^{-4}$	$5 \times 10^{-7}$	$1.0 \times 10^{-3}$
Average ratio			$1.0 \times 10^{-3}$
Sulfapyridine	$9 \times 10^{-4}$	$1 \times 10^{-3}$	$1.1 \times 10^{-3}$
	$5 \times 10^{-4}$	$5 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$2 \times 10^{-4}$	$2 \times 10^{-3}$	$1.0 \times 10^{-3}$
	$1 \times 10^{-4}$	$1 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$5 \times 10^{-5}$	$5 \times 10^{-7}$	$1.0 \times 10^{-3}$
Average ratio			$1.0 \times 10^{-3}$
Sulfadiazine	$9 \times 10^{-4}$	$1 \times 10^{-4}$	$1.1 \times 10^{-4}$
	$5 \times 10^{-4}$	$5 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$2 \times 10^{-4}$	$2 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$1 \times 10^{-4}$	$1 \times 10^{-4}$	$1.0 \times 10^{-3}$
	$5 \times 10^{-5}$	$5 \times 10^{-7}$	$1.0 \times 10^{-3}$
Average ratio			$1.0 \times 10^{-3}$
Sulfathiazole	$9 \times 10^{-4}$	$3 \times 10^{-4}$	$3.0 \times 10^{-4}$
	$7 \times 10^{-4}$	$2 \times 10^{-4}$	$2.9 \times 10^{-4}$
	$5 \times 10^{-4}$	$1 \times 10^{-4}$	$2.0 \times 10^{-4}$
	$3 \times 10^{-4}$	$7 \times 10^{-4}$	$2.3 \times 10^{-4}$
	$2 \times 10^{-4}$	$5 \times 10^{-4}$	$2.5 \times 10^{-4}$
	$1 \times 10^{-4}$	$3 \times 10^{-4}$	$3.3 \times 10^{-4}$
	$8 \times 10^{-5}$	$3 \times 10^{-4}$	$3.7 \times 10^{-4}$
Average ratio			$2.8 \times 10^{-4}$

Sulf—sulfonamide.

P.a.b.a.—p-aminobenzoic acid.

the range of each titration experiment This relationship may be expressed mathematically as follows

$$(1) \quad \frac{(\text{P a. b a.})}{(\text{Sulf})} = K$$

or

$$(2) \quad (\text{P a. b a.}) = K (\text{Sulf})$$

in which (P.a.b.a.) = molar concentration of *p*-aminobenzoic acid  
 (Sulf) = molar concentration of sulfonamide drug  
 $K$  = a constant.

Equation (2) plotted on Cartesian coordinates represents a straight line, with slope  $K$ , passing through the origin Since the absolute values for  $K$  (as shown in Table I) are extremely small, the titration curves cannot be conveniently plotted arithmetically, their slopes being so small that they practically lie upon the  $x$  axis The results of each titration experiment can, however, be graphed on a logarithmic scale as shown in Fig 2 It will be noted that the data thus plotted fall on straight lines parallel to one another and running at an angle of  $45^\circ$  with the axis These lines all approximate very closely the general equation

$$(3) \quad \log (\text{P a. b. a.}) = \log (\text{Sulf}) + \log K$$

which will be recognized as the logarithmic variant of equation (2) expressing the same linear relationship between drug and *p*-aminobenzoic acid

Two facts regarding the significance of the constant  $K$  deserve special emphasis

(a) The constant is equal to the molecular ratio of *p*-aminobenzoic acid and sulfonamide drug at the arbitrary end point chosen for the titration experiments Under standard conditions it defines the amount of *p*-aminobenzoic acid needed to nullify the antibacterial effect of a given quantity of drug

(b) The absolute value of  $K$  will vary with the type of organism, the size of the inoculum, the conditions under which the organism is grown, and the potency of the bacteriostatic agent employed If all but the last of these variables is kept rigidly constant, as in the present experiments, the magnitude of  $K$  becomes an index of the relative bacteriostatic power of the drug tested Under these conditions it is justifiable to refer to  $K$  as the "bacteriostatic constant"

As shown in Table II the bacteriostatic constants of the various sulfonamide compounds vary over a relatively wide range of values It will be noted that the more potent the drug the greater is the value of its bacteriostatic constant  $K$ , and, likewise, the lower its *p*-aminobenzoic acid titration curve falls on the

logarithmic graph (Fig 2) Thus the bacteriostatic constant of sulfathiazole, the most potent drug studied, is 0.028, whereas that of sulfanilamide, the least active, is only 0.00062

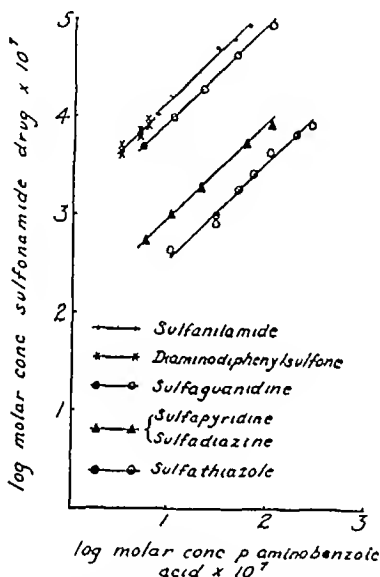


FIG 2 *p*-Aminobenzoic acid titration curves of sulfonamide drugs. Visible growth of *B. coli* (in 10 cc. of a synthetic medium) used as arbitrary end point for each titration. Inoculum standardized at 10 000 organisms and final readings made at the end of 5 days incubation at 37°C. Curves plotted for convenience on logarithmic coordinates.

It is of interest to compare the relative values obtained for  $K$  with the bacteriostatic potency of the drugs measured by the usual method, i.e. by determining the minimum concentration needed to cause bacteriostasis in the absence of additional *p*-aminobenzoic acid. The two sets of values may best be compared by using sulfanilamide as a standard and determining the "sulfanilamide coefficient" as shown in Table II. The data reveal a remarkably close correlation between the sulfanilamide coefficients determined by the two

methods<sup>5</sup> This close correlation is of considerable theoretical significance since it suggests that the bacteriostatic potency of each of the sulfonamide compounds is directly proportional to its ability to neutralize the action of the *p*-aminobenzoic acid added to the culture medium

In summary it may be stated that a quantitative study of the interaction of various sulfonamide drugs with *p*-aminobenzoic acid has revealed the following The antibacterial effect of each sulfonamide compound studied, regardless of chemical structure, was neutralized by the addition of *p*-aminobenzoic acid to the culture medium The amount of *p*-aminobenzoic acid needed to prevent-

TABLE II

*Sulfanilamide Coefficients of Various Sulfonamide Drugs Determined Both by Measuring the Minimum Bacteriostatic Concentration and by Titrating with p-Aminobenzoic Acid*

Sulfonamide drug	Minimum molar conc of drug causing bacteriostasis	Bacteriostatic constant, $K$ or Molar conc. Pa b.a. Molar conc. Sulf (Pa b.a titration)	Sulfanilamide coefficients	
			Min. bact. conc. S Min. bact. conc. X	$\frac{K_s}{K_x}$
Sulfanilamide	0.0004	0.00062	1	1.0
Diaminodiphenylsulfone	0.0002	0.00072	2	1.2
Sulfaguanidine	0.0002	0.001	2	1.6
Sulfapyridine	0.00002	0.01	20	16.1
Sulfadiazine	0.00002	0.01	20	16.1
Sulfathiazole	0.000008	0.028	50	45.2

$K$ , bacteriostatic constant determined by titration with Pa.b.a. (See average ratios, Table 1)

Pa b.a., *p*-aminobenzoic acid.

Sulf, sulfonamide drug

Min. bact. conc S, minimum molar concentration of sulfanilamide causing bacteriostasis.

Min. bact. conc. X, minimum molar bacteriostatic concentration of sulfonamide drug being compared with sulfanilamide

$K_s$ , bacteriostatic constant of sulfanilamide

$K_x$ , bacteriostatic constant of sulfonamide drug being compared with sulfanilamide.

bacteriostasis was directly proportional to the relative bacteriostatic potency of the drug Over a wide range of drug concentrations the minimum amount

<sup>5</sup> The *p*-aminobenzoic acid titration method is considered the more accurate of the two since the absolute value for  $K$  is obtained by averaging the numerous end points on the titration curve rather than by determining a single end point as in the simple bacteriostasis method. It should be emphasized, however, that neither of these *in vitro* methods can be relied upon at present to estimate the relative therapeutic effectiveness of untried sulfonamide compounds The sulfanilamide coefficients listed above have been measured under highly specialized conditions, namely, in an inhibitor-free medium, it does not necessarily follow that the relative bacteriostatic potency of the drugs will be the same in a more complex culture medium or in the animal body

of *p*-aminobenzoic acid needed to nullify the bacteriostasis was such that the ratio of *p*-aminobenzoic acid to the drug was constant. The *p*-aminobenzoic acid titration curve for each sulfonamide drug thus followed a linear relationship. The implications of these facts in relation to the possible mode of action of the sulfonamide drugs are considered significant and will be discussed below.

#### DISCUSSION

The important investigations of Woods on the mechanism of action of sulfanilamide were based on the working hypothesis that "antibacterial substances act by interfering with some substance essential to the bacterial cell." Having demonstrated that *p*-aminobenzoic acid in minute quantities neutralized the bacteriostatic effect of sulfanilamide and sulfapyridine, Woods suggested that the essential substance was *p*-aminobenzoic acid or a closely related compound. It is noteworthy, however, that at the time of his publication there was no direct experimental evidence that *p*-aminobenzoic acid was essential to bacterial metabolism, this evidence being supplied later by workers in other laboratories (8-10). Woods suggested further that sulfanilamide and sulfapyridine, because of their close chemical similarity to *p*-aminobenzoic acid, prevent bacterial growth by competing with the latter compound for the bacterial enzyme normally involved in its utilization. As evidence for this concept, he pointed out that the slightest deviation from the chemical structure of *p*-aminobenzoic acid greatly reduces the potency of the antisulfonamide effect, just as any change in the *p*-amino structure of sulfanilamide decreases its bacteriostatic properties. In addition he drew attention to other examples in enzyme chemistry of "competitive inhibition" due apparently to similarity of chemical structure. It should be emphasized that Woods' experimental data did not conclusively prove his theory which was presented only as a guide to further investigation.

The results of the studies reported in the present paper add important direct evidence in favor of Woods' theory. It was observed that *p*-aminobenzoic acid would neutralize the bacteriostatic properties of all of the six sulfonamide compounds studied, regardless of the differences in their chemical structure, and it was found also that the amount of *p*-aminobenzoic acid needed to prevent bacteriostasis was directly proportional to the bacteriostatic potency of the drug, provided all other variables were held constant. Both of these observations suggest that the bacteriostatic mechanism<sup>6</sup> of the sulfonamide

<sup>6</sup> It is of interest that the sulfonamide portion of the molecule rather than the *p*-amino nucleus appears to be responsible for certain of the toxic reactions caused by these drugs. The  $-\text{SO}_2\text{NH}_2$  radical of sulfanilamide inactivates carbonic anhydrase (14), and this fact has been offered as an explanation for sulfanilamide acidosis (15). Patients becoming sensitive to one sulfonamide drug are often found insensitive to others (16), an observation suggesting that the sensitivity phenomena are caused by some part of the molecule other than the *p*-amino nucleus which is common to all of the compounds.

drugs works mainly, if not entirely, through the *p*-amino nucleus which is common to *p*-aminobenzoic acid and to all of the drugs tested. The fact that an organism made "drug fast" to sulfathiazole is found to be resistant to the action of other sulfonamide compounds (17) also substantiates this concept.

In addition, the quantitative study of the interaction of *p*-aminobenzoic acid and the various sulfonamide drugs in bacterial cultures revealed that over a wide range of drug concentrations the minimum amount of *p*-aminobenzoic acid needed to prevent bacteriostasis was such that the ratio of *p*-aminobenzoic acid to drug remained constant. Woods previously had observed, in similar experiments, a constant ratio of *p*-aminobenzoic acid to drug when sulfanilamide was added to cultures of *B. coli* or *Streptococcus hemolyticus*, and while the present work was in progress Rubbo and Gillespie reported the same observation with sulfanilamide and *Cl. acetobutylicum*. In none of those experiments, however, were drugs other than sulfanilamide investigated.<sup>7</sup>

The linear relationship between drug and *p*-aminobenzoic acid is of considerable theoretical significance since it suggests that bacteriostasis is accomplished through the "competitive inhibition" (19) of an essential enzyme reaction by a substance chemically related to the substrate. Assuming the substrate to be *p*-aminobenzoic acid (or a closely related compound) and the inhibitor to be the sulfonamide drug, an equation expressing the same straight-line relationship may be derived on purely theoretical grounds as follows:

If *p*-aminobenzoic acid (*P*) and sulfanilamide, or one of its derivatives (*S*), compete for the same bacterial enzyme (*E*), the interaction of *P* and *S* with *E* may be expressed by the equations



Since the concentrations of *P* and *S* are infinitely large compared to that of *E*,<sup>8</sup> it may be assumed that practically all of the available enzyme is bound either by *P* or *S* and, therefore, may be considered to be equivalent to  $(PE) + (SE)$ . The amount of available enzyme is constant at the start of each experiment (constant inoculum of bacteria), so that

$$(3) \quad (PE) + (SE) = k_1$$

<sup>7</sup> Strauss, Lowell, and Finland (18) studied sulfanilamide, sulfapyridine, and sulfathiazole, and although they concluded that a linear relationship existed between drug and inhibitor, their data do not bear out this conclusion, since the curve obtained for each drug is a straight line only when plotted on semilogarithmic coordinates.

<sup>8</sup> The concentration of *P* and *S* ranged from 1 to  $10^{-6}$  mg per cc, whereas the concentration of bacteria introduced in the inoculum was 1,000 organisms (or approximately 10 to 12 mg) per cc. Even if it is assumed that the entire bacterial cell functions as active enzyme and that the relatively small *p*-aminobenzoic acid and sulfonamide molecules combine weight for weight with the much larger enzyme molecule, there is still a tremendous discrepancy between the amount of available enzyme and the concentrations of *P* and *S*.



The ability of the organism to multiply depends upon a certain minimum amount of *p*-aminobenzoic acid combining with enzyme to form the essential complex *PE*. At the selected titration end point only the minimum amount of *PE* needed to initiate growth is present at the start of the experiment, and, therefore, at this point (*PE*) may be considered a fixed quantity,  $k_2$ . It follows that

$$(4) \quad (PE) = k_1$$

and

$$(5) \quad (SE) = k_1 - k_2$$

At the titration end point the proportions of enzyme bound by *P* and *S* at the start of each experiment will be determined by two factors (a) the relative affinities of *P* and *S* for the enzyme, *E*, and (b) the relative amounts of *P* and *S* in the medium. The affinities of *P* and *S* for the enzyme are determined by the chemical properties of the compounds and may be considered constant in any one experiment, although the enzyme affinities of the different sulfonamide drugs probably vary with their chemical structure (12). It follows then that the relative concentrations of *PE* and *SE* are directly proportional to the relative concentrations of *P* and *S*. That is,

$$(6) \quad \frac{(PE)}{(SE)} = k_3 \frac{(P)}{(S)}$$

and

$$(7) \quad \frac{(P)}{(S)} = \frac{k_2}{k_1(k_1 - k_2)}$$

Since (*PE*) and (*SE*) are infinitely small as compared with (*P*) and (*S*), the terms (*P*) and (*S*) may be considered equivalent to the total amounts of *p*-aminobenzoic acid (P.a.b.a.) and sulfonamide drug (Sulf.) added to the medium.

$$(8) \quad \frac{(\text{P.a.b.a.})}{(\text{Sulf.})} = K$$

The last equation given expresses precisely the linear relationship observed experimentally. The close agreement between the theoretical equation and the experimental data adds strong evidence in favor of the assumption that the sulfonamide drugs and *p*-aminobenzoic acid compete for the same enzyme site on the bacterial cell.<sup>9</sup>

If *p*-aminobenzoic acid is essential for bacterial growth, and the sulfonamide drugs, through their chemical similarity to this essential metabolite, succeed in blocking the enzyme system normally involved in its utilization, it obviously follows that the bacteria will not grow. The fact that one molecule of *p*-aminobenzoic acid will antagonize the action of several thousand molecules of drug

<sup>9</sup> Since the completion of this manuscript Wyss (20) has published similar experiments with *p*-aminobenzoic acid and sulfanilamide and has reached the same conclusion through a different type of mathematical analysis.

does not invalidate this theory as to the mechanism of bacteriostasis, it may only indicate that the essential metabolite has a far greater affinity for the enzyme than has the drug, in which case a great excess of drug will be required to block the essential metabolite from its bacterial enzyme. The well known lag in the bacteriostatic action of the drug (21) may be explained by assuming that the supply of *p*-aminobenzoic acid already in the medium (and possibly combined with bacterial enzyme) must become inadequate before the rate of bacterial growth will be noticeably affected.

In conclusion it should be emphasized that although the experiments reported in the present paper strongly substantiate Woods' theory as to the mechanism of action of the sulfonamide drugs, the final proof of the theory must await the identification and careful study of the enzyme system (or systems) involved in the utilization of *p*-aminobenzoic acid.

#### SUMMARY

The following observations have been made which substantiate the theory that the sulfonamide drugs used in the treatment of bacterial infections exert their bacteriostatic effect by competing with the essential metabolite, *p*-aminobenzoic acid, for an important enzyme site on the bacterial cell.

- 1 *p*-Aminobenzoic acid was shown to nullify the bacteriostatic effect of all of the six sulfonamide compounds studied even though the drugs exhibited marked differences in chemical structure.

- 2 The bacteriostatic potency of each sulfonamide drug was found to be directly proportional to its ability to counteract the antibacteriostatic action of *p*-aminobenzoic acid.

- 3 In the case of each drug tested over a wide range of concentrations the minimum amount of *p*-aminobenzoic acid needed to prevent bacteriostasis was such that the ratio of *p*-aminobenzoic acid to drug was constant.

- 4 The linear relationship between *p*-aminobenzoic acid and drug was interpreted as indicating the competitive inhibition of an essential enzyme reaction by a substance chemically related to the substrate. This interpretation was supported by the fact that the equation derived on purely theoretical grounds relating drug and acid expressed the same linear relationship as that observed experimentally.

#### BIBLIOGRAPHY

- 1 Lockwood, J. S., *J. Immunol.*, 1938, 35, 155
- 2 Locke, A., Main, E. R., and Mellon, R. R., *Science*, 1938, 88, 620
- 3 Mayer, R. L., *Bull. Acad. Méd.*, 1937, 117, 727
- 4 Woods, D. D., *Brit. J. Exp. Path.*, 1940, 21, 74
- 5 Stamp, T. C., *Lancet*, 1931, 2, 10
- 6 Green, H. N., *Brit. J. Exp. Path.*, 1940, 21, 38
- 7 Fildes, R., *Lancet*, 1940, 1, 955

8. Rubbo, S. D , and Gillespie, J N , *Nature*, 1940 146, 838.
- 9 Lampen, J O , and Peterson, W H., *J Am Chem Soc* , 1941, 63, 2283
10. Park C. R., and Wood, W B , Jr , *Bull Johns Hopkins Hosp* , in press.
- 11 MacLeod, C. M , *J Exp Med* , 1940, 72, 217
- 12 Wood, W B , Jr , and Austrian, R., *J Exp Med* , 1942, 75, 383
- 13 Bliss, E A , and Long, P H , *Bull Johns Hopkins Hosp* , 1941, 49, 14.
14. Mann, T , and Keilin, D , *Nature*, 1940, 146, 164.
- 15 Wood, W B , Jr , and Favour, C. B , *J Clin Inv* , 1941, 20, 433
- 16 Davidson, A., and Bullova, J G M , *New England J Med* , 1940, 223, 811
- 17 Strauss, E., Dingle, J H , and Finland, M., *J Immunol.* 1941, 42, 331
18. Strauss, E., Lowell, F C , and Finland, M , *J Clin Inv* , 1941, 20, 189
- 19 Haldane, J B S , *Enzymes*, Monographs on biochemistry, London Longmans, Green and Co., 1930
- 20 Wyss, O , *Proc Soc Exp Biol. and Med* , 1941, 48, 122
- 21 Chandler, C. A , and Janeway, C. A., *Proc Soc Exp Biol and Med* , 1939, 40, 179



## STUDIES ON THE ANTIBACTERIAL ACTION OF THE SULFONAMIDE DRUGS

### II. THE POSSIBLE RELATION OF DRUG ACTIVITY TO SUBSTANCES OTHER THAN *p*-AMINO BENZOIC ACID\*

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The relation of *p*-aminobenzoic acid to the mode of action of the sulfonamide drugs has been discussed in the preceding paper (1). During the past year the theory has been advanced that sulfapyridine and sulfathiazole prevent bacterial growth by interfering with the functioning of chemically related coenzyme systems. Fildes (2) first called attention to the chemical relation of sulfapyridine to nicotinic acid and of sulfathiazole to thiamin. West and Coburn (3) also noted the similarity of sulfapyridine and nicotinic acid amide and reported *in vitro* experiments with *Staphylococcus aureus* on the basis of which they suggested that sulfapyridine exerts its bacteriostatic effect by interfering with the formation of cozymase from nicotinamide. Dorfman and his associates (4) observed that sulfapyridine inhibited the respiration of "resting" (5) dysentery bacilli and concluded that it acted by disturbing the respiratory function of the chemically related vitamin, nicotinamide. Using pyridine-3-sulfonic acid and its amide, rather than sulfapyridine, McIlwain (6) showed that sulfonic acid derivatives of nicotinic acid, when added to cultures of *Staphylococcus aureus* in a synthetic medium, inhibited the growth promoted by nicotinic acid, nicotinamide, and cozymase.

The attractiveness of the hypothesis that the group attached to the sulfonamide radical interferes with the functioning of certain vitamins and coenzymes is obvious when one considers the structural similarity of the compounds involved. Sulfapyridine, nicotinic acid, nicotinamide, and cozymase each possess a pyridine nucleus. The thiazole ring common to thiamin and cocarboxylase is contained in the sulfathiazole molecule, and sulfadiazine is similarly related to thiamin and cocarboxylase through its pyrimidine radical. Since nicotinic acid, thiamin, and their corresponding coenzymes are known to play important rôles in bacterial metabolism (7), it seems logical to assume that they may be

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concerned in the bacteriostatic action of the chemically related sulfonamide compounds

To prove the hypothesis, however, it is necessary first to demonstrate that the antisulfonamide effect of the vitamin or its coenzyme is specific in the sense that it antagonizes only the chemically related sulfonamide drug. For example nicotinic acid and cozymase should inhibit sulfapyridine but not sulfathiazole, sulfadiazine, or sulfanilamide. Thiamin and cocarboxylase, on the other hand, should block the action of sulfathiazole and sulfadiazine but should not influence the action of sulfapyridine or sulfanilamide. The experiments reported in the present paper indicate that the antisulfonamide effect of thiamin, nicotinamide, and their respective coenzymes is in no sense specific and is due to stimulation of bacterial growth rather than to a direct antagonistic action upon the sulfonamide drugs. These observations are discussed in relation to the mode of action of the complex derivatives of sulfanilamide, and a tentative explanation is offered for the variations in bacteriostatic potency exhibited by the different sulfonamide compounds

### Material and Methods

**Culture Media**—The medium used in all experiments with *Staphylococcus aureus* was one of known chemical composition described by Gladstone (8). The constituents of the medium and the several fractions, which were sterilized separately by autoclaving or filtering, are listed in Table I. All of the labile fractions (part B) were added separately in the order designated. In the experiments with *B. coli* the medium used was that described in the preceding paper.

**Drug, Vitamin, and Coenzyme Solutions**—Solutions of the various vitamins and coenzymes<sup>1</sup> used in the bacteriological experiments were prepared by dissolving each substance either in the basal amino acid fraction of the staphylococcal medium or in the synthetic medium for *B. coli*, depending upon the organism to be used. The vitamins and coenzymes tested, and the final concentrations in which they were employed, are designated below under each experiment. The solutions were sterilized by filtration through Seitz filters. Solutions of sulfanilamide, sulfapyridine, sulfathiazole, thionine, and methylene blue were prepared in a similar manner except that instead of being filtered, the basal medium was brought to a boil just before the drug was added and the solution was then allowed to cool slowly without further heating. Stock solutions of the sulfonamide compounds and of methylene blue were made up in concentrations of  $10^{-2}$  or  $10^{-3}$  molar, whereas thionine was prepared in a saturated solution. The desired concentrations for each experiment were attained by diluting the stock solutions with the appropriate basal medium.

**Organisms**—The strain of *Staphylococcus aureus* used was one isolated from a routine throat culture. The organism was transferred from blood agar to 5 cc. of Gladstone's amino acid medium to which nicotinamide and thiamin had been added in final concentrations of  $10^{-5}$  and  $10^{-7}$  molar respectively. Excellent growth was

<sup>1</sup> Cocarboxylase and cozymase were supplied through the courtesy of Merck and Company

obtained in this synthetic medium, and daily subcultures were made by adding 0.1 cc. of a 24 hour culture to 5 cc. of the medium. The inoculum used in all experi-

TABLE I  
*Culture Medium for Staphylococcus aureus*

A. Basal amino acid fraction	
KH <sub>2</sub> PO <sub>4</sub>	4.5 gm.
Water	550 ml.
NaOH 1N	26 ml.
S-Aspartic acid	0.20 gm.
S-Valine	0.15 gm.
S-Leucine	0.15 gm.
S-Alanine	0.10 gm.
S-Glutamic acid	0.10 gm.
S-Iso-Leucine	0.10 gm.
S-Phenylalanine	0.10 gm.
S-Lysine hydrochloride	0.10 gm.
S-Glycine	0.05 gm.
L(-) Proline	0.05 gm.
L(-)-Oxyproline	0.05 gm.
L(-)-Tyrosine	0.05 gm.
L(+)-Arginine hydrochloride	0.05 gm.

Amino acids dissolved in the buffer solution made up to 600 ml., adjusted to pH 7.40, tubed in 3 ml. quantities and autoclaved.

B. Labile fractions (added to each tube separately)	
L(-) Cystine, M/200 in M/10 HCl (Seitz filter)	0.10 ml.
NaOH M/5 (autoclave)	0.05 ml.
S-Methionine, M/100 (Seitz filter)	0.10 ml.
L(-) Tryptophane, M/200 (autoclave)	0.05 ml.
Glucose M/2 (Seitz filter)	0.05 ml.
MgSO <sub>4</sub> 7H <sub>2</sub> O M/60 (autoclave)	0.125 ml.
Fe(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> 6H <sub>2</sub> O M/500 in M/50 HCl (Seitz filter)	0.125 ml.
Water (autoclave)	1.4 ml.

C. Vitamin fraction

To make a basal medium for daily subculture and for bacteriostatic experiments, 0.5 cc. of a solution of  $10^{-4}$  M nicotinamide and  $10^{-6}$  M thiamin chloride dissolved in the basal amino acid fraction was added to each tube making final concentrations of  $10^{-4}$  and  $10^{-6}$  respectively.

ments was 0.1 cc. of a 1:10,000 dilution of the daily subculture. Plate counts revealed that the inoculum contained between 10,000 and 20,000 organisms, giving a final bacterial concentration of 2,000 to 4,000 viable organisms per cc. The strain of *B. coli* and the manner in which it was cultured in the synthetic medium have already been fully described in the previous paper.

## EXPERIMENTAL

*1 Determination of the Concentrations of Thiamin, Cocarboxylase, Nicotinamide, and Cozymase Optimal for the Growth of Staphylococcus aureus*

Knight's experiments (9) to determine the quantities of nicotinamide and of thiamin necessary for the optimal growth of the staphylococcus in Gladstone's synthetic medium were repeated, and it was found that  $10^{-6}$  M nicotinamide (or cozymase) and  $10^{-8}$  M thiamin (or cocarboxylase) would insure heavy growth in 42 hours when growth was estimated by noting the degree of clouding in the culture tubes. Growth curves revealed, however, that still higher concentrations of any of these four substances would cause more rapid multiplication of the organism (Figs 1 A, 1 B, and 1 C). Knight's assertion that  $10^{-6}$  M nicotinamide and  $10^{-7}$  M thiamin enabled optimal growth to occur was, therefore, not confirmed in the case of the present strain of staphylococcus. That increasing concentrations of nicotinamide, cozymase, thiamin, and cocarboxylase accelerate the growth rate of the staphylococcus is a fact of primary importance in interpreting the antibacteriostatic effect of these compounds to be described below.

*2 Determination of the Minimum Concentrations of Sulfanilamide, Sulfapyridine, Sulfathiazole, Thiamine, and Methylene Blue That Will Prevent the Growth of Staphylococcus aureus*

The minimum bacteriostatic concentrations of the various drugs used were determined by adding increasing concentrations of drug to successive tubes and noting the smallest concentration that would inhibit growth completely for 48 hours.<sup>2</sup> This end point was measured with a reasonable degree of accuracy by allowing the concentrations in consecutive tubes to vary only within relatively narrow limits. The concentrations of sulfanilamide in several consecutive tubes were, for example,  $6 \times 10^{-4}$  M,  $4 \times 10^{-4}$  M,  $2 \times 10^{-4}$  M,  $1 \times 10^{-4}$  M, etc. The end points of the sulfonamide drugs were very constant when the same lots of medium and of drug solution were used. New medium and new drug solution, when standardized, showed a maximum shift in drug end point of only one tube. The dye end points were less constant, showing a tendency to shift one or two tubes in successive experiments. To eliminate the significance of any possible variation, the position of the drug or dye end point was checked in all subsequent experiments dealing with bacteriostasis. The minimum bacteriostatic concentrations of the various agents tested are listed in Table II.

<sup>2</sup> Macroscopically detectable growth



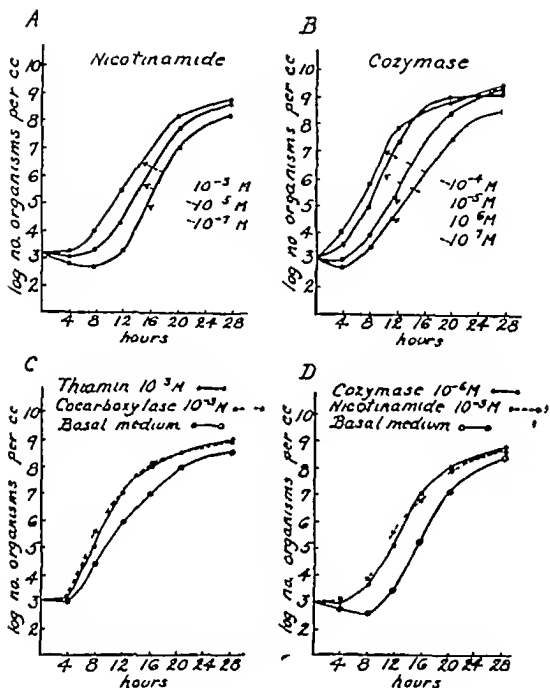


FIG 1

A. Growth curves of *Staphylococcus aureus* in synthetic medium containing increasing concentrations of nicotinamide.

B Growth curves of *Staphylococcus aureus* in synthetic medium containing increasing concentrations of cozymase.

C. Growth curves of *Staphylococcus aureus* in synthetic medium containing high concentrations of thiamin and cocarboxylase.

D Comparison of the growth rates of *Staphylococcus aureus* in  $10^{-3} M$  nicotinamide and in  $10^{-6} M$  cozymase.

### 3 The Antisulfonamide Effect of Nicotinamide, Cozymase, Thiamin, and Cocarboxylase

When *Staphylococcus aureus* was used as the test organism, it was found possible to block<sup>3</sup> the growth-inhibiting effect of sulfanilamide, sulfapyridine, and sulfathiazole with nicotinamide when the latter substance was added to the synthetic medium in a concentration of  $2 \times 10^{-3}$  molar. Lower concentrations of nicotinamide blocked more irregularly and a concentration of  $10^{-4}$  molar nicotinamide had no blocking effect whatsoever. Cozymase blocked the

TABLE II

*Minimum Bacteriostatic Concentrations of Sulfonamide Drugs, Methylene Blue, and Thionine As Tested against Staphylococcus aureus in a Synthetic Medium*

Sulfanilamide	$2 \times 10^{-4}$ M
Sulfapyridine	$8 \times 10^{-5}$ M
Sulfathiazole	$1 \times 10^{-5}$ M
Methylene blue	$1 \times 10^{-6}$ M (approximate)
Thionine	1:160 dilution of saturated solution (approximate)

TABLE III

*Blocking of Bacteriostatic Action of Sulfapyridine and Sulfathiazole by Cozymase*

Sulfapyridine			Sulfathiazole		
Drug concentration	Basal medium	Cozymase $10^{-4}$ M	Drug concentration	Basal medium	Cozymase $10^{-4}$ M
$6 \times 10^{-5}$ M	+	+	$6 \times 10^{-5}$ M	+	+
$8 \times 10^{-5}$ M	0	+	$8 \times 10^{-5}$ M	0	+
$1 \times 10^{-4}$ M	0	+	$1 \times 10^{-4}$ M	0	+
$2 \times 10^{-4}$ M	0	0	$2 \times 10^{-4}$ M	0	0

+ indicates visible growth of *Staphylococcus aureus* at the end of 48 hours.

growth-inhibiting action of these same drugs far more effectively having an antibacteriostatic effect at concentrations between  $10^{-6}$  and  $10^{-7}$  molar (Table III). Thiamin and cocarboxylase, on the other hand, manifested only a barely detectable antidrug effect even at concentrations as high as  $10^{-3}$  molar. As suggested by the next experiment, this last result may be explained by the relatively slight degree of growth stimulation brought about by thiamin and cocarboxylase in the synthetic medium as compared to that caused by nicotinamide and cozymase.

In cultures of *B. coli* thiamin ( $10^{-3}$  M), riboflavin ( $10^{-5}$  M), pyridoxine

<sup>3</sup> The term "block" will be used only with reference to the prevention of bacteriostasis.

( $10^{-3}$  M), pantothenic acid ( $2 \times 10^{-4}$  M), crystallin biotin (3 $\gamma$  per cc.), crystallin methyl biotin<sup>4</sup> (3 $\gamma$  per cc.), nicotinamide ( $10^{-3}$  M) cocarboxylase  $10^{-3}$  M and cozymase  $10^{-4}$  M all failed to exert an antisulfonamide effect. All of these compounds also failed to increase the antibacteriostatic action of small amounts of *p*-aminobenzoic acid simultaneously added to the medium.

#### 4 *Correlation of the Antibacteriostatic Action of Nicotinamide, Cozymase, Thiamin, and Cocarboxylase with Their Ability to Stimulate Bacterial Growth*

Instead of influencing only the chemically related drug sulfapyridine, nicotinamide and cozymase were shown to block the bacteriostatic action of all three sulfonamide compounds. This observation suggested that the blocking effect might be due to stimulation of growth rather than to a direct antagonistic action upon the drug. An attempt was made to correlate the antibacteriostatic effect of nicotinamide and cozymase with their ability to stimulate growth. The rate of growth of the staphylococcus in basal medium was compared to that in medium containing from  $10^{-3}$  to  $10^{-6}$  molar nicotinamide or from  $10^{-4}$  to  $10^{-7}$  molar cozymase. It can be seen from the resulting growth curves (Figs. 1A and 1B) that the stimulating effect of cozymase is much greater than that of nicotinamide. As stated above, the limiting blocking concentration of nicotinamide, i.e. the lowest concentration that will reverse the inhibition of growth by a sulfonamide drug, is approximately  $10^{-3}$  molar whereas that of cozymase is between  $10^{-3}$  and  $10^{-7}$  molar. If the growth rates of the staphylococcus in  $10^{-3}$  molar nicotinamide and in  $10^{-3}$  molar cozymase are plotted on the same graph (Fig. 1D), it can be seen that they are approximately the same, indicating a close correlation between the growth promoting properties and the drug blocking effect of the compounds.

Similar experiments were also carried out with *B. coli* grown in the synthetic medium described in the preceding paper. Neither nicotinamide nor cozymase is a growth factor for *B. coli* as each is for *Staphylococcus aureus*, and repeated growth curves showed that cozymase did not stimulate the growth of *B. coli* in the synthetic medium. Failing to stimulate growth, cozymase, even in concentrations of  $10^{-4}$  molar, failed also to block the action of any of the sulfonamide drugs. It appears, therefore, that the antibacteriostatic action of nicotinamide and cozymase is dependent upon acceleration of bacterial growth rather than upon a direct antidrug effect.

#### 5 *Lack of Specificity in the Antibacteriostatic Effect of Cozymase*

Quantitative experiments were carried out to determine whether or not the blocking effect of cozymase was greater against sulfapyridine to which it is

<sup>4</sup> Obtained through the courtesy of Professor V. du Vigneaud, Cornell University Medical School.

chemically related than against sulfanilamide or sulfathiazole to which it is unrelated. The degree of blocking by cozymase of each of the compounds was found to be approximately the same (Table III).

To determine whether or not the antibacteriostatic action of cozymase bore any specific relation to the sulfonamide group of drugs, cozymase was titrated against thionine and methylene blue. Both of these compounds are dyes which probably achieve their bacteriostatic effect by altering the oxidation-reduction potential of the culture medium (10), a mechanism apparently quite different from that by which the sulfonamide drugs act (1). Cozymase blocked the growth-inhibitory effect of thionine regularly. Less satisfactory results were obtained with methylene blue because of the instability of the bacteriostatic end point of this dye, but the general result was the same as with thionine. These experiments are compatible with the view that the drug-blocking effect of cozymase is unrelated to the chemical structure of the drug involved and merely results from the stimulation of bacterial growth.

#### 6 *The Failure of Sulfanilamide, Sulfapyridine, and Sulfathiazole to Affect the in Vitro Action of Cocarboxylase As a Coenzyme*

Cocarboxylase is known to function as a coenzyme in the decarboxylation of pyruvate by the enzyme carboxylase contained in yeast. The activity of cocarboxylase may be conveniently estimated by measuring manometrically in the Warburg apparatus the rate of evolution of  $\text{CO}_2$  from a carboxylase-cocarboxylase-pyruvate mixture. The method employed in the present studies was that of Lohmann and Schuster (11), the reaction being carried out at a pH of 6.6<sup>5</sup>. The possible inhibitory action of sulfanilamide, sulfapyridine, and sulfathiazole upon the functioning of cocarboxylase was tested by carrying out the reaction in the presence of a final concentration of 10 mg. per cent of drug. Although sulfathiazole, which is chemically related to cocarboxylase, was added in concentrations 50 to 200 times greater than that of the coenzyme, it failed to influence the reaction. Sulfanilamide and sulfapyridine likewise were without effect. In preliminary unpublished experiments with sulfapyridine and the cozymase-apozymase system, Walti also failed to detect any inhibitory effect of the drug upon the action of the coenzyme (12).

#### DISCUSSION

Direct evidence has been presented in the preceding paper supporting the theory that the sulfonamide drugs prevent bacterial growth by interfering

<sup>5</sup> The dried yeast preparation used as a source of carboxylase and the sodium pyruvate were supplied through the courtesy of Dr. Otto Bessy of the Department of Biological Chemistry, Harvard Medical School. The authors are grateful to Dr. C. L. Gemmel of the Department of Physiology, Johns Hopkins Medical School, for the Warburg apparatus used in these studies.

with the metabolic function of *p*-aminobenzoic acid. According to this theory there are at least two possible explanations for the fact that some of the more common derivatives of sulfanilamide are considerably more potent bacteriostatic agents than the parent drug. First, the greater bacteriostatic powers of the substituted sulfonamide compounds, such as sulfapyridine, sulfathiazole, and sulfadiazine, may be explained by assuming that the radical attached to the sulfonamide group interferes with the metabolism of a second substance essential to the bacterial cell, just as the *p*-amino nucleus of these compounds apparently disturbs the function of *p*-aminobenzoic acid. Such a dual effect on the part of the more complex derivatives of sulfanilamide might well account for their increased bacteriostatic potency. Second, the greater antibacterial powers of the substituted sulfonamide compounds may be explained by assuming that the chemical group attached to the sulfonamide radical enables the compounds to interfere with the metabolism of *p*-aminobenzoic acid more effectively than does the simpler sulfanilamide molecule. According to this second hypothesis the only metabolic function of the bacterial cell interfered with by the sulfonamide compounds is that concerned with the utilization of *p*-aminobenzoic acid, the degree to which this function is disturbed determining the relative bacteriostatic potency of the drug.

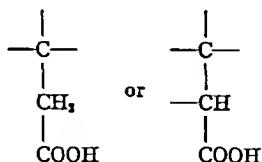
The first of these hypotheses has received support in the publications of Dorfman and his coworkers and of West and Coburn, who have advanced the view that sulfapyridine specifically alters the metabolism of the pyridine-containing coenzyme, cozymase. On purely theoretical grounds the same reasoning might be applied to sulfathiazole and sulfadiazine since both of these compounds are structurally similar to thiamin and its coenzyme, cocarboxylase. The results of the experiments reported in the present paper, however, fail to confirm the view that the chemical group linked to the sulfonamide radical plays a specific rôle in interfering with either the formation or the function of the analogous coenzyme. It has been shown that the antisulfonamide effect of cozymase, emphasized by West and Coburn, is in no sense specific but is due to its action as a growth stimulant rather than to a directly antagonistic action against the drug.<sup>6</sup> Also the *in vitro* activity of the coenzyme, cocarboxylase, was found to be unaffected by the chemically related sulfonamide compound, sulfathiazole, even when the latter was present in concentrations 200 times greater than the coenzyme. Both of these observations cast grave doubt upon the attractive theory that the bacteriostatic effect of sulfapyridine, sulfathiazole, and sulfadiazine is related to their structural

<sup>6</sup> It should be pointed out that *p*-aminobenzoic acid blocks efficiently the sulfonamide drugs in a medium in which it fails to stimulate growth (1). The dissociation of growth stimulation and antidrug effect would appear to be fundamental in determining whether a given chemical compound is specifically related to the mechanism of bacteriostasis.

similarity to nicotinamide, thiamin, and the respective coenzymes. The results likewise fail to substantiate the view that the greater antibacterial power of the more complex sulfonamide drugs is due to a dual effect upon the metabolism of the bacterial cell as compared to the single effect exerted by the simpler sulfanilamide molecule.

The second hypothesis advanced to explain the differences in bacteriostatic potency exhibited by the various common sulfonamide drugs is, on the other hand, entirely compatible with the observations reported in the previous paper. *p*-Aminobenzoic acid was shown to block the bacteriostatic effect of all of the sulfonamide compounds studied, regardless of their chemical structure, and the bacteriostatic potency of each drug was found to be directly proportional to its ability to nullify the blocking effect of *p*-aminobenzoic acid. Both of these observations suggest that all of the sulfonamide drugs studied cause bacteriostasis by interfering with a single metabolic function of the bacterial cell, namely that concerned with *p*-aminobenzoic acid.

Evidence has been presented also that the drugs exert their bacteriostatic effect by competing with *p*-aminobenzoic acid for the enzyme system normally involved in its utilization. If the mechanism of bacteriostasis concerns only the competitive inhibition of this particular enzyme system, it must be assumed that the relative bacteriostatic power of a given sulfonamide drug depends upon its relative ability to disturb the function of this essential system. Such an assumption is not without foundation for analogous variations in competitive inhibition by related chemical compounds are common in enzyme chemistry. For example, Quastel and Wooldridge (13) have shown that various organic acids having in common the structure



inhibit the important respiratory enzyme, succinic dehydrogenase. The authors have attributed the inhibition to the structural similarity of these compounds and the specific substrate, succinic acid, and have postulated that the common chemical configuration causes the inhibitors to become adsorbed on to that part of the enzyme surface which normally adsorbs and activates the substrate. Quastel and Wooldridge have demonstrated in addition that all of the related acids do not cause the same degree of inhibition, the inhibitory effect being quantitatively different in the case of each compound, presumably because of a specific degree of affinity for the enzyme. Thus the present hypothesis advanced to explain the mode of action of the sulfonamide drugs may be considered exactly analogous to the competitive inhibition of succinic dehydrogenase, for the experimental evidence strongly suggests that

sulfanilamide and its derivatives, due to their chemical similarity to *p*-aminobenzoic acid, competitively inhibit the enzyme involved in its utilization and that different sulfonamide drugs inhibit this essential enzyme reaction in different degrees.

To prove conclusively this "unitarian theory" as to the mechanism of sulfonamide bacteriostasis it will be necessary first to identify the enzyme system that utilizes *p*-aminobenzoic acid and secondly to demonstrate that the relative bacteriostatic power of a given sulfonamide drug is directly proportional to its ability to inhibit this particular enzyme system. An attempt is now being made to identify the enzyme (or enzymes) involved in this apparently vulnerable cycle of bacterial metabolism.

#### SUMMARY

1 In cultures of *Staphylococcus aureus* in a synthetic medium nicotinamide and cozymase were shown to block the bacteriostatic action of chemically unrelated sulfonamide drugs as well as the chemically related compound sulfapyridine. The antibacterial properties of organic dyes totally unrelated to the sulfonamide compounds (methylene blue and thionine) were also nullified by the addition of cozymase to the culture medium.

2 The antagonistic action of the pyridine-containing coenzyme, cozymase, was found, by quantitative study, to be no greater against sulfapyridine than against other structurally dissimilar sulfonamide compounds.

3 The antidrug effects of nicotinamide and cozymase in staphylococcus cultures were observed to be directly proportional to their ability to stimulate the growth of the organism in the synthetic medium. When tested in cultures of *B. coli* in which they failed to accelerate bacterial growth, these same substances failed to influence the bacteriostatic action of the sulfonamide drugs.

4 The *in vitro* action of the coenzyme, cocarboxylase, as measured in the Warburg respirometer, was shown to be unaffected by the chemically related drug, sulfathiazole, even when the latter was present in great excess.

The above observations fail to support the theory that sulfapyridine, sulfathiazole, and sulfadiazine prevent bacterial growth by interfering with the functioning of the chemically related coenzymes, cozymase, and cocarboxylase. The mode of action of sulfanilamide and its more common derivatives is discussed in the light of these observations, and a tentative theory is offered to explain the differences in bacteriostatic potency exhibited by the various sulfonamide compounds.

#### BIBLIOGRAPHY

- 1 Wood, W B Jr, *J Exp Med*, 1942 76, 369
- 2 Fildes, P, *Lancet*, 1940, 1, 955
- 3 West R., and Coburn, A. F *J Exp Med*, 72, 91, 1940

- 4 Dorfman, A , Rice, L , Koser, S A , and Saunders, F , *Proc Soc Exp Biol and Med* , 1940, **45**, 750
- 5 Quastel, J H , and Whetham, M D , *Biochem J* , 1925, **19**, 520
- 6 McIlwain, H., *Brit J Exp Path* , 1940, **21**, 136
- 7 Stephenson, M., *Bacterial metabolism*, London, Longmans, Green and Co , 1939
- 8 Gladstone, G P , *Brit J Exp Path* , 1939, **20**, 189
- 9 Knight, B C J G , *Biochem J* , 1937, **31**, 96
- 10 Dubos, R., *J Exp Med* , 1929, **49**, 575
- 11 Lohmann, K , and Schuster, P , *Biochem Z* , 1937, **294**, 188
- 12 Walti, A , personal communication
- 13 Quastel, J H , and Wooldridge, W R , *Biochem J* , 1928, **22**, 689



# STUDIES ON THE PURIFICATION OF POLIOMYELITIS VIRUS

## I. YIELDS AND ACTIVITY OF PREPARATIONS OBTAINED BY DIFFERENTIAL CENTRIFUGATION\*

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The application of high speed differential centrifugation to the purification of poliomyelitis virus has been a logical step since Stanley and Wyckoff (1) showed that relatively small and unstable plant viruses could be isolated as homogeneous materials by this method. The sedimentation of poliomyelitis virus in an ultracentrifuge was first demonstrated by Schultz and Raffel (2), and more recently Clark, Rasmussen, and White (3) obtained sediments which showed an irregular but in some instances high virus activity. While it has been shown that high speed centrifugation resulted in a sedimentation of the virus, evidence has not been provided that other macromolecular materials associated with normal tissue were not also sedimented along with the virus under these conditions. In view of the work of several investigators (4-6) on the concentration of macromolecular materials from various normal animal tissues, such constituents might very well be present together with virus in the high molecular weight fractions obtained from poliomyelitis-infected tissues.

This paper presents the results of experiments on the application of differential centrifugation to the extracts of glycerolated or frozen, infected medullae-cords from *rhesus* monkeys and to similar extracts of glycerolated or frozen, normal medullae-cords. The results show that when extracts of infected as well as normal cords, that have been stored in glycerol, are subjected to high speed centrifugation, appreciable yields of high molecular weight substances are obtained. However, when normal tissue that had been frozen and stored for appreciable lengths of time was used, no significant amount of high molecular weight, nitrogen-containing compounds was recovered. Frozen infected tissue, on the contrary, yielded small but significant amounts of high molecular weight material possessing both a high and uniform virus activity.

### EXPERIMENTAL

Purification of the virus by differential centrifugation requires (1) the preparation of large quantities of infectious extract free from tissue fragments

\* Aided by a grant from The National Foundation for Infantile Paralysis, Inc.

and lipoidal material, (2) the separation of the virus from soluble constituents of low molecular weight, and (3) the separation of the virus from high molecular weight substances which are thrown down with the virus in the ultracentrifuge. The first step was accomplished by suspending the infected cords in buffer by means of a Waring blender, by centrifuging the tissue suspension at 3800 R.P.M. in a large angle centrifuge, by extracting the supernatant liquid with ether, and then by filtering the aqueous extracts through celite. The virus was sedimented, and aggregated colloidal material was removed by centrifugation in an air-driven centrifuge of the improved Pickels' design<sup>1</sup> (7). The virus used was the M V strain mixed with a strain provided by Dr Charles Armstrong in 1936 and carried in monkeys since then by Dr E W Schultz. The details of the procedure which was applied both to infected and normal tissues are as follows.

The spinal cord and medulla from each animal was removed aseptically and either dropped into a 1-1 glycerol-0.1 M phosphate buffer mixture at pH 7 and stored in a refrigerator or placed in a large test tube (25 × 200 mm.) and stored in a freezing chamber at -10°C. About 100 gm. of the pooled glycerolated tissue, drained free of the glycerol-phosphate solution, or the same amount of the frozen tissue, and 200 ml. of buffer cooled to 0°C were mixed in the blender for 3 minutes. During this time, the temperature of the mixture increased to about 15°C, and it was necessary to cool the container in ice before mixing was continued. In this way the suspension was mixed for a total of about 15 minutes. It was then transferred to 100 ml. centrifuge bottles and centrifuged at 3800 R.P.M. in an angle centrifuge in a room maintained at 2°C until a relatively clear supernatant fluid was obtained. The time necessary varied with the solvent used. About 1½ hours were necessary when Ringer's solution was used and about 3 to 4 hours when water or 0.05 M phosphate or 0.01 M borate buffer was used. The supernatant fluid was pipetted off, and the residue again transferred to the blender and extracted as before with an additional 100 ml. of ice-cold solvent for about 3 minutes. This suspension was centrifuged in the angle centrifuge, and the supernatant fluid removed as before. In this way a third, fourth, and in many cases a fifth extract was prepared.

The extracts, which at this stage were milky in appearance, were combined and extracted in a separatory funnel with one-half a volume of ether. An emulsion was obtained which was broken in the angle centrifuge into an ether layer, a middle layer of semisolid gelatinous material, and a clear aqueous bottom portion. The aqueous layer was removed, and the semisolid material re-extracted once with buffer. The amount of this semisolid material varied greatly with the buffer used in preparing the original extract. It was decreased to a thin skin-like layer in each centrifuge tube when Ringer's or physiological salt solution was used but was as thick as a centimeter when the tissue was extracted with water or dilute buffer. The extracts were now almost water clear with the exception of a few particles of solid which were removed by filtration through a thin layer of a mixture of approximately equal

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<sup>1</sup>The authors are indebted to Dr E G Pickels for providing photographic copies of scale drawings of the driving mechanism.

parts of Hyflo and Standard supercel. The filtrate from either infected or normal cords was a clear liquid usually slightly pink in color due to the presence of small amounts of hemoglobin. That from poliomyelitic tissues was infectious in about 100 per cent of the monkeys infected intracerebrally with 1 ml. of a 1 to 1000 dilution based on the weight of cords extracted.

A volume of the clear filtrate equal to 112 ml., in eight stainless steel tubes was centrifuged at 600 R.P.S. for 1½ hours in a dowmetal head similar in design to that described by Wyckoff and Lagsdin (8). The head was cooled to 0°C at the beginning of a run and warmed up to about 10°C after 1½ hours. The average centrifugal force was about 79 000 × gravity. After a centrifugation run the supernatant liquid was carefully pipetted off and replaced with an equal amount of the clear extract, which was in turn centrifuged at 600 R.P.S. In this way the high molecular weight

TABLE I

*Examples of Analyses of Supernatant Liquids after Successive Sedimentations of High Molecular Weight Constituents at 600 R.P.S.*

Experiment No.	Amount and type of starting material	Total nitrogen in					
		Original extract	Supernatant liquids from successive centrifugations				
			First	Second	Third	Fourth	Fifth
		mg	mg	mg	mg	mg	mg
6	100 gm. glycerolated virus cords		269	0.63	0.11		
19	88 gm. frozen normal cords	245	229	3.4	0.80	0.30	0.26
20	85 gm. frozen virus cords	272	268	1.74	0.36	0.14	0.035
22	44 gm. frozen virus cords	187	180	1.67	0.47	0.19	0.14
23	103 gm. frozen virus cords	205	196	1.23	0.16	0.031	0.011

With the exception of Experiment 22, the pooled tissues were obtained from *rhesus* monkeys. In Experiment 22 the tissues were obtained from *cynomolgus* monkeys. The solvents used were as follows: in Experiment 6, 0.05 M phosphate at pH 7.5, in Experiments 19 and 22, 0.01 M borate at pH 7.8, and in Experiments 20 and 23 Ringer's solution. Nitrogen determined by method of Levy and Palmer (9).

materials in the extract from 100 gm. of tissue and in some cases from 200 gm. was concentrated into eight tubes. The sediments were combined and resuspended in about 28 ml. of solvent. Aggregated colloidal particles were removed from this solution in the air-driven centrifuge by running it at a speed of 500 R.P.S. for a few minutes. The supernatant fluid and the wash liquid from the sediment obtained after a similar run up and down were then subjected to a second sedimentation run at 600 R.P.S. for 1½ hours. The supernatant liquid was pipetted off the sediment resuspended in buffer and aggregated material again removed as before.

Analyses of the supernatant liquids from each successive sedimentation showed that the amount of unsedimentable nitrogen decreased and was insignificant after the fourth sedimentation. Most preparations were, therefore, subjected to four centrifugal cycles of purification before they were considered free from low molecular weight constituents. Examples of the amounts of nitrogen present in successive supernatant liquids from extracts of infected and normal tissues when phosphate, borate, or Ringer's solution was used are shown in Table I.

The sediment obtained after four sedimentations was dissolved in a small volume of solvent, the solution was centrifuged at slow speed to remove any insoluble residue, and an aliquot was analysed for total nitrogen by the method of Levy and Palmer (9). Aseptic technique was used throughout the purification procedures and the temperature was kept as near 0°C as possible. The time required for the preparation of the extracts and for the purification of the high molecular weight constituent from 100 gm. of tissue averaged about 10 days.

#### *Recovery of Virus Activity after Ultracentrifugation*

To determine the efficiency of the above described method in sedimenting the virus and to obtain a rough measure of the loss of virus in the discarded supernatant liquids, a sample of infectious filtrate was subjected to three centrifugal cycles of purification. This involved sedimentation, removal of the supernatant liquid and re-solution of the sedimented material in fresh solvent. The activity of the sediment was compared with that of a similar quantity of filtrate, which had been treated in the same way with the exception that the sediment was redissolved each time in the original supernatant liquid. The results found in three experiments are shown in Table II.

*Activity Tests*—In all cases in which a preparation was tested for virus activity, 1 ml. of the dilution or concentration tested was injected intracerebrally into *rhesus* monkeys under ether anesthesia. The dilutions were prepared immediately before inoculation in the same buffer used for the extraction of the infected tissues. After injection the animals were observed daily for tremors and the onset of a flaccid paralysis. Those which developed paralysis were sacrificed within a day or two after the paralysis had become extensive. In a few cases in which animals died during the incubation period without showing paralysis, histological examinations were made of the medulla and cord. If typical lesions were found, the test was considered positive. Animals which failed to develop poliomyelitis within 3 weeks after injection were counted negative, and were used again in later experiments. These monkeys almost without exception finally came down with poliomyelitis.

It can be seen that the amount of virus activity present in the sediment obtained after one or three centrifugal cycles of purification was approximately the same as that of the original extract or of the control in which the sediment was redissolved each time in the original supernatant liquid. The amount of virus aggregated because of packing in the centrifuge or lost in the discarded supernatant liquids was not sufficiently great, therefore, to be detected by these infectivity measurements. Several experiments on the activity of the supernatant liquids obtained after a run at 600 R P S gave results which led to the same conclusion. The supernatant liquid was infectious in only a small percentage of the animals injected with doses of 1 ml. Before ultracentrifugation, 1 ml. of the clarified extracts was usually infectious at a dilution of about 1:120.

*Yields of High Molecular Weight Materials from Glycerolated and Frozen Infected and Normal Tissues*

The yields of sedimentable nitrogen obtained from poliomyelitis-infected and normal cords when subjected to the above described procedures are

TABLE II

*Recovery of Poliomyelitis Virus Activity after Centrifugation at 600 R.P.S. for 1½ Hours*

	Dilutions (based on weight of tissue extracted)			
	1 500	1 1000	1 2000	1-4000
1 Original extract. Experiment 1	++*	++	+-	+-
2. Original extract centrifuged and sediment resuspended in supernatant liquid Experiment 1	++	+-	--	--
2	++	+-	++	+-
3 Original extract centrifuged, supernatant liquid discarded, and sediment resuspended in volume of buffer equal to that of supernatant liquid. Experiment 1	++	+-	++	--
2		+-	+-	--
4. Once-sedimented virus treated two additional times as in 2 Experiment 1	++	+-	++	++
2	++	+-	--	+-
" 3	++	+-	++	
5 Once-sedimented virus treated two additional times as in 3 Experiment 1	++	+-	++	+-
" 2	++	+-	+-	+-
3	++	++	++	

In Experiments 1 and 2 Waring blender extracts before ether extraction were used. In Experiment 3 the extract was further clarified by ether extraction, etc. In Experiments 1, 2, and 3 the buffer consisted of 0.01 molar borate at pH 7.8 distilled water and Ringer's solution without glucose respectively.

\* Each + sign indicates that the monkey developed poliomyelitis. Each - sign indicates that the monkey failed to develop poliomyelitis within 3 weeks, but later either proved susceptible or died from other causes.

shown in Table III. Data are included for tissues that had either been stored in glycerol at 5°C or kept in the frozen state at -10°C. To provide a measure of the length of time the tissues were stored in each experiment, the average age of the pool is given. This was obtained by dividing the total length of time all the cords in a pool were stored by the number present. The number of

cords, in most experiments, and the dates they were removed and the extracts prepared are as follows

*Experiment 7*—Aug 15, 1938, to Nov 18, 1939 Extracted Apr 22, 1940, Experiment 11 May 15 to June 2 Extracted June 19, 1940, Experiment 16 Aug 9

TABLE III

*Yields of High Molecular Weight Constituents from Infected and Normal Tissues*

Type of tissue	Method of storage	Experiment No.*	Average length of time tissue was stored	Time required for purification	Amount of tissue ground	No of sedimentations	Yield (nitrogen)	Yield nitrogen per 100 gm. tissue
			days	days	gm		mg	mg
Infected	In 50 per cent glycerol-phosphate at 5°C	7	386†	30	107	4	0.97	0.91
		11	26	20	195	3	0.95	0.49
		16	42	8	92	3	2.1	2.3
		17	140	77	85	4	0.57	0.67
		27	283	11	209	3	0.98	0.47
Infected	In stoppered tubes without solvent at -10°C	20	81	6	85	5	0.15	0.18
		21	145	8	70	3	<0.01	<0.01
		22	7	8	44	5	0.51	1.16
		23	85	9	103	5	0.078	0.076
		24	105	10	170	3	0.12	0.071
		26	30	12	186	3	0.19	0.10
		28	9	8	170	3	1.0	0.59
		29	13	17	73	4	0.16	0.22
		30	19	8	93	3	0.39	0.42
Normal	In 50 per cent glycerol phosphate at 5°C	31	54	13	57	3	0.22	0.39
Normal	In stoppered tubes without solvent at -10°C	19	4	10	70	5	2.74	3.91
		25	54	10	111	3	0.04	0.036
		32	34	4	112	3	0.18	0.16

\* Experiments 19, 20, 22, and 23 are the same experiments referred to in Table I. The solvents used in the other experiments were as follows: 7, 11, and 16, 0.05 M phosphate at pH 7.5; 17, 0.01 M sodium borate at pH 7.8; 21, Ringer's solution, in all other experiments Ringer's solution without glucose.

† The cords in this pool were collected in connection with earlier studies carried out by Professor E. W. Schultz.

to Oct. 14, Extracted Oct. 23, 1940, Experiment 17 June 1 to July 8 Extracted Nov. 9, 1940, Experiment 19 One each on Feb. 7 and 9, three on Mar. 19, and five on Mar. 20 Extracted Mar. 21, 1941, Experiment 20 One each on Dec. 4, 5, 13, 27, 28, and 30, 1940, and Mar. 7, 1941, and two each on Jan. 6 and Mar. 6 Extracted Apr. 4, 1941, Experiment 21 One each on Nov. 17, 28, and 29, and three each on Nov. 16 and 20, 1940 Extracted Apr. 15, 1941, Experiment 22 Three on Apr.

21 and five each on Apr 20 and 22 Extracted Apr 28, 1941, Experiment 23 Five on Nov 13, 1940, one each on Mar 8 9, 11, and Apr 17, two on Apr 19, and four on Apr 20 Extracted May 14, 1941 Experiment 24 Nine on Nov 14 and three on Nov 15, 1940, one each on May 8, 10, 12, 16, and 18, three on May 14, two each on May 15 and 17 Extracted May 29, 1941, Experiment 25 One each on Mar 25, Apr 16, 22, and June 10, two on May 24 and four on July 15 Extracted July 21, 1941, Experiment 26 May 21 to July 22 Extracted July 25, 1941, Experiment 27 One each on Oct. 15 16 24, 25, 26, Nov 8 9, and 11, two each on Oct. 21 and Nov 4, and four on Nov 12 1940 Extracted Aug 11, 1941, Experiment 28 One each on July 23 Aug 6, 22 23 and 26, two each on Aug. 24 and 25 three on Aug 8 and five each on Aug 14 and 16 Extracted Aug 27, 1941 Experiment 29 Five each on Aug 26 and 27 Extracted Sept. 9, 1941, Experiment 30 One each on Aug 26 and Sept 19, three on Sept. 20, and six on Sept. 22. Extracted Oct. 8, 1941, Experiment 31 One each on June 24, July 18 19, and Oct. 8, two on Oct. 7 Extracted Oct. 21, 1941, Experiment 32 One each on Aug 14 and Nov 4, two each on Aug 4 Oct. 9 and 28, three on Oct. 10, and four on Oct. 30 Extracted Nov 11, 1941

Appreciable amounts of high molecular weight materials were obtained from both glycerolated normal and infected tissues regardless of the length of time the tissues were stored. The results with frozen tissues, in general, show a striking decrease in the amounts of high molecular weight substances present. It is evident, however, that the yield varies, depending on the period of storage. In Experiments 22 and 28, in which the cords had been stored for only a short time relatively large quantities of high molecular weight materials were obtained. In contrast to these, in Experiments 21, 23, and 24, in which the tissues had been kept for from 2 to 5 months on the average, only small yields of sedimentable nitrogen were isolated. As shown in Experiments 19, 25, and 32, similar results were obtained with normal tissue stored at  $-10^{\circ}\text{C}$ . While the number of the latter experiments is not sufficiently large to lead to a final conclusion, the data suggest that such storage has a more pronounced effect on the high molecular weight constituent present in the normal than in the infected cords.

#### *Virus Activity of Sediments from Glycerolated and Frozen Infected Tissue*

The virus activities of the sediments from glycerolated and frozen infected cords were determined by finding the minimum quantity in terms of nitrogen, which would produce typical poliomyelitis when injected intracerebrally into normal *rhesus* monkeys. The results found for eleven different preparations are shown in Table IV. It can be seen that with the exception of Experiment 22, infections were regularly obtained with  $5 \times 10^{-8}$  gm. of nitrogen of the virus sediment in a volume of 1 ml., when the infected tissue had been frozen before extraction. In most cases some infection was also obtained with  $5 \times 10^{-10}$  gm. The regular infective dose when glycerolated tissue was used was  $5 \times 10^{-8}$  to  $5 \times 10^{-7}$  gm., and only about 30 per cent of the animals tested with  $5 \times 10^{-9}$

cords, in most experiments, and the dates they were removed and the extracts prepared are as follows

*Experiment 7*—Aug 15, 1938, to Nov 18, 1939    Extracted Apr 22, 1940, Experiment 11    May 15 to June 2    Extracted June 19, 1940, Experiment 16    Aug 9

TABLE III

*Yields of High Molecular Weight Constituents from Infected and Normal Tissues*

Type of tissue	Method of storage	Experiment No *	Average length of time tissue was stored	Time required for purification	Amount of tissue ground	No of sedimentations	Yield (nitrogen)	Yield nitrogen per 100 gm. tissue
			days	days	gm		mg	mg
Infected	In 50 per cent glycerol-phosphate at 5°C.	7	386†	30	107	4	0 97	0 91
		11	26	20	195	3	0 95	0 49
		16	42	8	92	3	2 1	2 3
		17	140	77	85	4	0 57	0 67
		27	283	11	209	3	0 98	0 47
Infected	In stoppered tubes without solvent at -10°C	20	81	6	85	5	0 15	0 18
		21	145	8	70	3	<0 01	<0 01
		22	7	8	44	5	0 51	1 16
		23	85	9	103	5	0 078	0 076
		24	105	10	170	3	0 12	0 071
		26	30	12	186	3	0 19	0 10
		28	9	8	170	3	1 0	0 59
		29	13	17	73	4	0 16	0 22
Normal	In 50 per cent glycerol-phosphate at 5°C	30	19	8	93	3	0 39	0 42
		31	54	13	57	3	0 22	0 39
		19	4	10	70	5	2 74	3 91
		25	54	10	111	3	0 04	0 036
		32	34	4	112	3	0 18	0 16

\* Experiments 19, 20, 22, and 23 are the same experiments referred to in Table I. The solvents used in the other experiments were as follows 7, 11, and 16, 0.05 M phosphate at pH 7.5, 17, 0.01 M sodium borate at pH 7.8, 21, Ringer's solution, in all other experiments Ringer's solution without glucose.

† The cords in this pool were collected in connection with earlier studies carried out by Professor E. W. Schultz.

to Oct 14, Extracted Oct 23, 1940, Experiment 17    June 1 to July 8    Extracted Nov 9, 1940, Experiment 19    One each on Feb 7 and 9, three on Mar 19, and five on Mar 20    Extracted Mar 21, 1941, Experiment 20    One each on Dec 4, 5, 13, 27, 28, and 30, 1940, and Mar 7, 1941, and two each on Jan. 6 and Mar 6    Extracted Apr 4, 1941, Experiment 21    One each on Nov 17, 28, and 29, and three each on Nov 16 and 20, 1940    Extracted Apr 15, 1941, Experiment 22    Three on Apr



21 and five each on Apr 20 and 22 Extracted Apr 28, 1941, Experiment 23 Five on Nov 13, 1940, one each on Mar 8, 9, 11, and Apr. 17, two on Apr 19, and four on Apr 20 Extracted May 14, 1941 Experiment 24. Nine on Nov 14 and three on Nov 15, 1940, one each on May 8, 10, 12, 16, and 18, three on May 14, two each on May 15 and 17 Extracted May 29, 1941, Experiment 25 One each on Mar 25, Apr 16, 22, and June 10, two on May 24, and four on July 15 Extracted July 21, 1941, Experiment 26 May 21 to July 22 Extracted July 25, 1941, Experiment 27 One each on Oct. 15, 16, 24, 25, 26, Nov 8, 9, and 11, two each on Oct. 21 and Nov 4, and four on Nov 12 1940 Extracted Aug 11, 1941 Experiment 28 One each on July 23, Aug 6, 22, 23, and 26, two each on Aug. 24 and 25, three on Aug 8 and five each on Aug 14 and 16 Extracted Aug 27, 1941 Experiment 29 Five each on Aug. 26 and 27 Extracted Sept. 9, 1941 Experiment 30 One each on Aug 26 and Sept. 19, three on Sept 20, and six on Sept. 22. Extracted Oct. 8, 1941, Experiment 31 One each on June 24, July 18, 19, and Oct. 8, two on Oct. 7 Extracted Oct. 21, 1941, Experiment 32 One each on Aug 14 and Nov 4, two each on Aug 4, Oct. 9 and 28, three on Oct. 10, and four on Oct. 30 Extracted Nov 11, 1941

Appreciable amounts of high molecular weight materials were obtained from both glycerolated normal and infected tissues regardless of the length of time the tissues were stored. The results with frozen tissues, in general, show a striking decrease in the amounts of high molecular weight substances present. It is evident, however, that the yield varies, depending on the period of storage. In Experiments 22 and 28, in which the cords had been stored for only a short time, relatively large quantities of high molecular weight materials were obtained. In contrast to these, in Experiments 21, 23, and 24, in which the tissues had been kept for from 2 to 5 months on the average, only small yields of sedimentable nitrogen were isolated. As shown in Experiments 19, 25, and 32, similar results were obtained with normal tissue stored at  $-10^{\circ}\text{C}$ . While the number of the latter experiments is not sufficiently large to lead to a final conclusion, the data suggest that such storage has a more pronounced effect on the high molecular weight constituent present in the normal than in the infected cords.

#### *Virus Activity of Sediments from Glycerolated and Frozen Infected Tissue*

The virus activities of the sediments from glycerolated and frozen infected cords were determined by finding the minimum quantity in terms of nitrogen, which would produce typical poliomyelitis when injected intracerebrally into normal *rhesus* monkeys. The results found for eleven different preparations are shown in Table IV. It can be seen that with the exception of Experiment 22, infections were regularly obtained with  $5 \times 10^{-8}$  gm. of nitrogen of the virus sediment in a volume of 1 ml., when the infected tissue had been frozen before extraction. In most cases some infection was also obtained with  $5 \times 10^{-10}$  gm. The regular infective dose when glycerolated tissue was used was  $5 \times 10^{-8}$  to  $5 \times 10^{-7}$  gm., and only about 30 per cent of the animals tested with  $5 \times 10^{-9}$

gm developed poliomyelitis. In so far as it is possible to compare these results, therefore, the use of frozen tissue resulted in material about ten times as active as that obtained from glycerolated tissue. The activity found in Experiment 22 can be explained by the fact that in this case the cords had been stored for an average of only 7 days, and the sedimentable nitrogen probably consisted of the normal component as well as of virus. This explanation would also account for the relatively large yield of the high molecular substances found

TABLE IV  
*Activities of Individual Preparations from Glycerolated and Frozen Tissues*

Experiment No.	Method of storage	Average length of time stored	Concentration injected (gm nitrogen per ml)							
			$5 \times 10^{-4}$	$5 \times 10^{-7}$	$5 \times 10^{-8}$	$5 \times 10^{-9}$	$2.5 \times 10^{-9}$	$1 \times 10^{-9}$	$5 \times 10^{-10}$	$5 \times 10^{-11}$
6	In 50 per cent glycerol-phosphate at 5°C	days								
11		345				++--†	---			
16		26		+-	+-	--				
17		42	+++	++-	++-	+-				
20	In stoppered tubes without solvent at -10°C	140	+++	+++	++-	+-				
21		81	+++	+++	+++	+++			+-	---
22		145			+	+			-	
23		7		+++	++	++-			---	
24		85		++	++	++	++	+-	+-	
26		105			++	++			--	
30		30		+++	+++	++		---	+-	
		19			++	++			++	

\* The experiment numbers refer to the same experiments listed in Table III. In Experiment 20 the tests at  $5 \times 10^{-11}$  and  $5 \times 10^{-10}$  gm nitrogen per ml. were made when the sample was 27 days old. In Experiment 21 the dilutions were made assuming a nitrogen concentration of 0.01 mg per ml. In Experiment 24, the activity tests were made after the sample had stood at about 5°C for 67 days.

† See footnote, Table II.

in this experiment. The constituent from normal cords failed to produce symptoms of disease when doses corresponding to  $5 \times 10^{-5}$  gm of nitrogen were injected intracerebrally.

#### *General Properties of the High Molecular Weight Constituents from Infected and Normal Tissues*

The products obtained after three or four sedimentations in the ultracentrifuge from either infected or normal tissues consisted of small, amber-colored, transparent pellets which dissolved completely in water or buffer solutions. In the case of glycerolated cords in which relatively large yields of high molec-

ular weight materials were found, the solutions were in most cases opalescent by reflected light and slightly yellow by transmitted light. The products obtained from frozen cord, regardless of whether they were infected or normal, were appreciably yellow but failed to show the characteristic opalescent appearance by reflected light. The virus concentrates, in two instances, were examined for streaming birefringence by allowing the solutions to flow from a

TABLE V  
*Stability of Purified Virus Preparations When Stored for Different Lengths of Time in Different Solvents*

Experiment No.	Length of time stored	Solvent used	Concentration injected (gm. nitrogen per ml.)							
			$1.5 \times 10^{-2}$	$5 \times 10^{-3}$	$2.5 \times 10^{-3}$	$5 \times 10^{-4}$	$10^{-4}$	$5 \times 10^{-5}$	$2.5 \times 10^{-5}$	$5 \times 10^{-6}$
6	1	0.05 molar phosphate at pH 7.5						++--*	----	
	26						+-	+-		
	51				--	+-	+-			
	88		+++	+						
16	5	0.01 molar borate at pH 7.8	+++	++-		++-		+-		
	21		+++	-		+-		---		
	25		+++	+-		---		---		
	50		++-	+++		---		---		
20	1	Ringer's solution pH 8	+++	+++		+++		+++		
	27			+++		+++		++-		+-
	95			++++		+++		++-		---

The sample obtained in Experiment 6 was prepared from glycerolated infected tissue with 0.05 molar phosphate buffer as the solvent. The samples in Experiment 16 and 20 are the same as those described in Table III. The three samples at concentrations of 0.1, 2.1 and 0.15 mg. nitrogen per ml. respectively were stored in stoppered tubes at about 5°C.

\* See footnote, Table II.

pipette held between crossed polaroid plates. In neither case was there evidence of double refraction of flow.

The purified virus preparations gave the Millon's test for protein. The nitrogen in one of the earlier, less active virus samples and that from a normal sample obtained in both cases from glycerolated material, was completely precipitated by trichloroacetic acid. Several samples from normal and infected cords were examined for phosphorus (10) and carbohydrate (11), and in all cases these constituents were found present. The nitrogen to phosphorus ratio for the normal constituents in the two preparations was 4.5 to 1, and for two virus samples it was 3.7 and 5.3 to 1. The carbohydrate (as glucose)

to nitrogen ratios for the same preparations were 1.1 and 1.3 for the normal samples and 1.2 and 0.3 for the virus samples. However, because the analyses were carried out on extremely small samples, the experimental error was large, and the values are not greatly significant except to demonstrate that both carbohydrate and phosphorus were present.

On the addition of one-half volume of saturated ammonium sulfate to solutions of either the virus-containing sediment (Experiment 30) or the normal constituent (Experiment 32), the solutions became turbid. On allowing them to stand overnight in the refrigerator, a yellow amorphous precipitate separated in both cases. That from the infected cord proved partly insoluble in water or in dilute phosphate buffer at pH 7. The precipitate from normal tissues dissolved completely in Ringer's solution, but its solubility was not determined in the above mentioned solvents.

The purified virus is relatively stable at about 5°C when dissolved in Ringer's solution. Table V shows the results of activity tests made on three preparations over a period of about 3 months. Some loss of activity probably took place after the solutions had stood for about 25 days, but even after 95 days in the case of the most active preparation (Experiment 20) there was sufficient activity remaining to infect the three animals tested at a concentration of  $5 \times 10^{-8}$  gm of nitrogen. The purified preparations do not retain their activity when dried from Ringer's solution in the frozen state and over phosphorus pentoxide at 40°C. One such preparation, for example, which was 100 per cent infective at a concentration of  $5 \times 10^{-9}$  gm of nitrogen before it was dried, failed to infect two monkeys at  $1.3 \times 10^{-8}$  gm after it was dried.

#### DISCUSSION

The experiments on extracts of normal spinal cords and medullae demonstrate that there is a high molecular weight constituent present and that it is sedimented in the ultracentrifuge under the conditions used to sediment the virus. Appreciable yields of this component were obtained either from glycerolated normal or infected tissues or from tissues that had been stored without glycerol at -10°C for a few days. Storage of normal tissue at -10°C for longer periods of time resulted in a decrease of this constituent, and after several weeks the amount present became almost negligible. Storage of infected tissue at -10°C likewise resulted in a decrease in the yield of sedimentable nitrogen, but small amounts of material were still obtained after the tissues had been stored for several months. The specific activity of the sediments under the latter conditions was about ten times that of the preparations obtained either from glycerolated or fresh, infected tissues. It appears, therefore, that the decrease in the yield of high molecular weight substances takes place at the expense of the normal constituent rather than of virus. The experiments on the recovery of virus activity after three ultracentrifugal

cycles of purification provide evidence that the amount of virus, which had become irreversibly aggregated after ultracentrifugation, was not appreciable.

The high and relatively uniform specific activity of the virus preparations obtained from cords that had been stored for several weeks suggests that they may consist of relatively pure virus. A more detailed study of the minimum period of storage necessary to eliminate the high molecular weight constituent completely from normal tissue and of the effect of storage on total virus activity is in progress. These experiments should provide additional information regarding the optimal conditions for obtaining the virus. Some direct evidence for the homogeneity of the purified preparations has been found from studies in the McBain transparent ultracentrifuge (12). In collaboration with Dr. Frances Wright, the homogeneity and sedimentation rate of several preparations were determined. The results, which will be presented in full in a later paper, show that relatively homogeneous preparations were obtained in experiments in which the infected tissues had been stored for several months. The average value for the sedimentation constant  $S_{w}^{25}$ , was  $62 \times 10^{-13}$ . It is of interest that this value is different from that of  $S_{w}^{30}$ ,  $160-170 \times 10^{-13}$  reported recently for the mouse encephalomyelitis virus by Gard and Pedersen (13). If further work definitely establishes the identity of the  $62 \times 10^{-13}$  component with the poliomyelitis virus, it would appear that the two viruses differ not only in immunological properties as shown by Theiler (14) but in sedimentation rate as well.

#### SUMMARY

Results of experiments on the preparation of high molecular weight constituents from normal and poliomyelitis-infected medullae-cords are presented. Relatively large yields were obtained from glycerolated normal or infected tissues or from tissues that had been stored at  $-10^{\circ}\text{C}$  for a few days. When the frozen tissues were stored for several weeks, the amount of sedimentable nitrogen isolated from the normal cords decreased and became almost negligible. Under these same conditions small but definite amounts of a high molecular weight material were isolated from the infectious extracts. This material regularly produced poliomyelitis when 1 ml. containing  $5 \times 10^{-9}$  gm. of nitrogen was injected intracerebrally into *rhesus* monkeys. The purified virus sediment contains nitrogen, phosphorus, and carbohydrate; it gives the Millon's test for protein, and is precipitated by one third saturation with ammonium sulfate. Results of ultracentrifugal analyses show that a relatively homogeneous component with  $S_{w}^{25} = 62 \times 10^{-13}$  is present.

The authors wish to thank Professor E. W. Schultz for much valuable advice, for examining the histological sections, and for providing many of the facilities of the Department of Bacteriology and Experimental Pathology for this work.

## BIBLIOGRAPHY

- 1 Stanley, W M , and Wyckoff, R W G , *Science*, 1937, **85**, 181
2. Schultz, E W , and Raffel, S , *Proc Soc Exp Biol and Med* , 1937, **37**, 297
- 3 Clark, P F , Rasmussen, A F , and White, W C , *J Bact* , 1941, **42**, 63
- 4 Wyckoff, R. W G , in Cold Spring Harbor symposia on quantitative biology, Cold Spring Harbor, Long Island Biological Association, 1938, **6**, 361
- 5 Claude, A., *Proc Soc Exp Biol and Med* , 1938, **39**, 398
- 6 Sharp, D G , Taylor, A R , Finkelstein, H , and Beard, J W , *Proc Soc Exp Biol and Med* , 1939, **42**, 459
- 7 Pickels, E G , *Rev Scient Instr* , 1938, **9**, 358
- 8 Wyckoff, R W G , and Lagsdin, J B , *Rev Scient Instr* , 1937, **8**, 74
- 9 Levy, M , and Palmer, A H , *J Biol Chem* , 1940, **136**, 57
- 10 King, E J , *Biochem J* , London, 1932, **26**, 292
- 11 Pirie, N W , *Brit J Exp Pathl* , 1936, **17**, 275
- 12 McBain, J W , and Lewis, A H , *J Physic Chem* , 1939, **43**, 1197
- 13 Gard, S , and Pedersen, K O , *Science*, 1941, **94**, 493
- 14 Theiler, M , *J Exp Med* , 1937, **65**, 705

## ON THE MECHANISM OF SPECIFIC PRECIPITATION

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It has been pointed out (13, 10, 17) that according to the "alternation" (= "mutual multivalence" = "lattice" = "framework") theory of serological reactions, simple chemical compounds, if they contain as many as two (or at any rate three) groups capable of reacting specifically with antibody, should be able to form precipitates when mixed with the appropriate antisera. It is apparent that such precipitation would not be expected on the basis of the views of Bordet (3) concerning serological reactions, with their emphasis on the covering of the surface of the antigen by a film of antibody.<sup>1</sup> Tests of this prediction of the alternation theory have been made (10, 11, 17) with results which are not in full agreement with the older (or the newer) theory. This raises the question if either point of view can be quite correct, and it is the purpose of the present communication to report the results of experiments designed to throw light on this question.

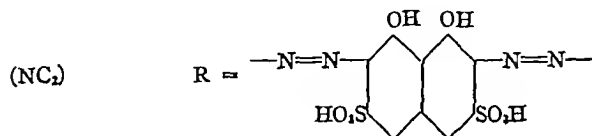
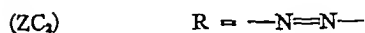
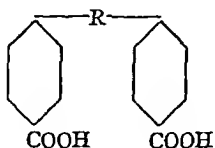
Pauling, Campbell and Pressman (17) have suggested that the failure of Hooker and Boyd (11) to obtain specific precipitation with their divalent haptens could be attributed in part to the small size of the molecules studied, stating that "Steric repulsion between two antibody molecules attached to such small molecules would be much stronger than for the molecules used by Landsteiner and van der Scheer and by us." It will be seen below that this can hardly be the true explanation, but in view of this suggestion, and in view of the fact that Hooker and Boyd failed to observe precipitation with compound "V" (see below), where  $R = -N=N-C_6H_4AsO_2H_2$ , but did with "VII," where  $R = -N=N-C_6H_4-N=N-C_6H_4AsO_2H_2$ , it was considered necessary to make compounds in which the reactive groups were about as far apart as in the latter compound.

In the course of this work 34 different compounds were made and tested. Seven of these had been previously studied (11, 17), the others had not been examined, and apparently the majority of them have been made here for the first time. We may divide the parent compounds on the basis of structure into

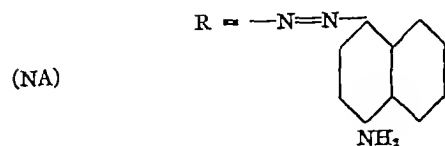
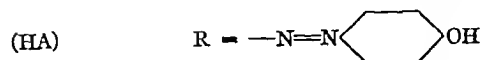
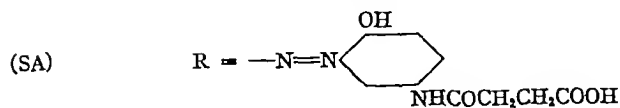
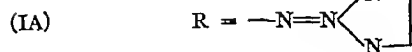
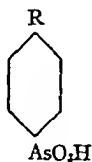
<sup>1</sup> Except presumably with rather large molecules such as polysaccharides or simple molecules which associate in solution to give larger particles.

five classes, I, II, III, IVA, and IVB, which have the composition shown below, where R represents the group which varied

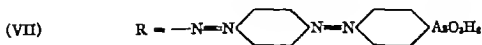
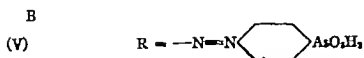
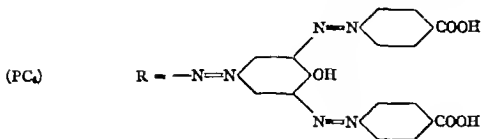
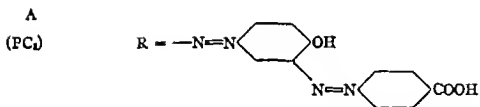
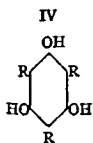
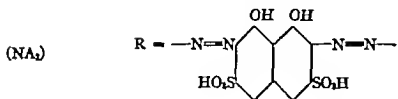
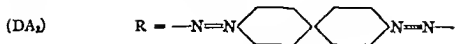
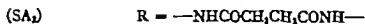
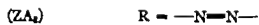
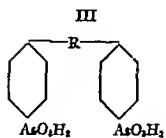
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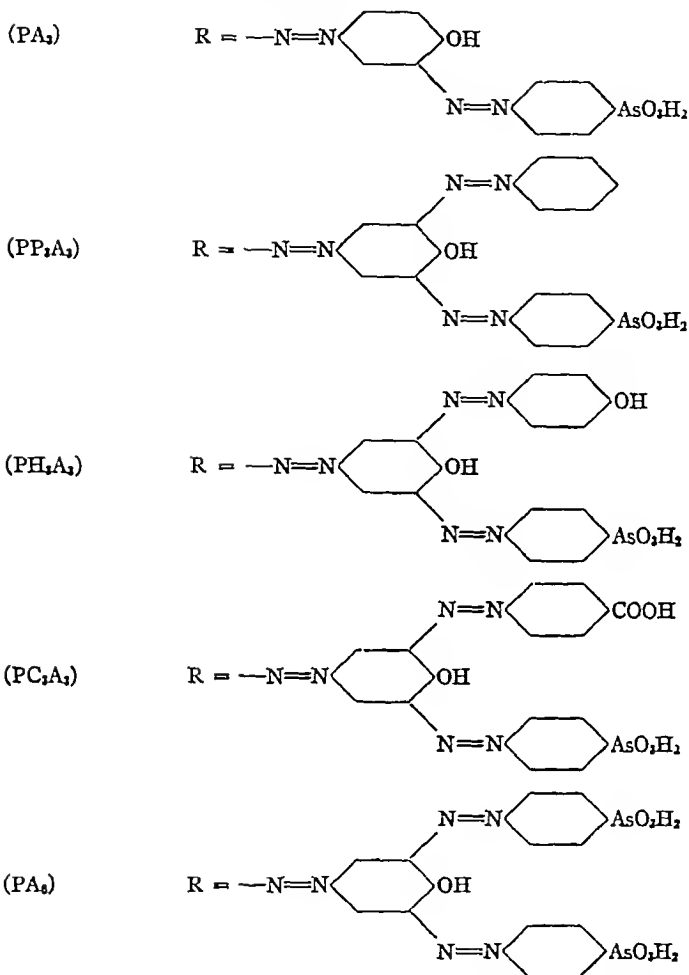


II









The combinations of letters in parentheses are shorthand designations for the various compounds, for convenience in reference. It will be noted that A represents the arsonic acid group, C the carboxylic acid group, Z the azo linkage, P phloroglucinol, etc. The compounds designated by the Roman numerals V and VII are the compounds thus numbered in the paper of Pauling, Campbell, and Pressman (17).

In addition to these compounds, the following were made by acetylating or benzoylating certain of the above (a represents acetyl, b, benzoyl) NAb, NA<sub>2</sub>b, PC<sub>2</sub>a, PC<sub>2</sub>b, PC<sub>4</sub>a, PC<sub>4</sub>b, PA<sub>2</sub>a, PA<sub>2</sub>b, PC<sub>2</sub>A<sub>2</sub>a, PC<sub>2</sub>A<sub>2</sub>b, PA<sub>4</sub>a, PA<sub>4</sub>b.

All the haptens were brought into solution as the sodium salt, by addition of the minimum of NaOH. The concentration of the stock solutions was in each case 1 mg/cc.

Tests with a few of the haptens brought to definite pH indicated that the exact pH of the solutions was not important, doubtless because the pH of the serum hapten mixtures is in all cases controlled almost completely by the relatively large buffer power of the serum.

### Materials and Methods

The preparation of compounds of class I has already been described (11). The compounds of class II were all made by coupling diazotized arsanilic acid with the appropriate substance. Of the compounds of class III  $\text{NA}_2$  has been described (11),  $\text{SA}_2$  was made as described by Morgan and Walton (14).  $\text{DA}_2$  was made by the Bart reaction from



Of the compounds of class IV, V was made by coupling three equivalents of diazotized arsanilic acid with phloroglucinol (17), VII by coupling three equivalents of diazotized *p*-amino-azobenzene arsonic acid (AA) with phloroglucinol. In addition to my own preparations of V and VII small samples were available which Drs. Pauling, Campbell, and Pressman kindly sent me prepared as described by them (17) no differences in behavior were observed. The other compounds were made by coupling three equivalents of diazotized *p*-amino phenol with phloroglucinol, purifying, then coupling to this in alkaline solution the appropriate amounts of other diazotized amines in the presence of pyridine (18). These compounds were purified first by repeatedly dissolving in alkali and precipitating with acid, then by crystallization from alcohol water mixtures.

The constitution of several of the arsenic-containing compounds was checked by drying and analyzing them for arsenic.

The antisera used in these experiments were of two kinds, designated as anti C and anti A. The former were made by injecting rabbits with *Limulus* hemocyanin coupled with diazotized *p*-amino-benzoic acid, the latter by injecting *Limulus* hemocyanin coupled with diazotized arsanilic acid. Four different anti C sera, each represented by two bleedings at different stages of immunization were available, viz., 161, 162, 163, 165. The corresponding anti A sera were 239, 241, 243, 244, 271. Two different bleedings from each of these rabbits were also available. The earlier bleedings seemed somewhat superior. The anti C sera contained about 0.2 mg. of antibody N per cc. the anti A sera about 0.3.

The tests for precipitability of the various haptens were made by mixing in small tubes 0.3 cc. of antiserum with 0.3 cc. of an appropriate dilution of the hapten allowing to stand overnight in the ice box then examining for precipitate. Controls consisting of hapten alone, hapten plus saline, and hapten plus normal rabbit serum were always included, and were consistently negative.

### RESULTS

None of these haptens were precipitated by any of the anti-C sera, in any of a large number of dilutions tested. The results with compounds of classes I and IVA were thus consistently negative.

None of the univalent arsenic-containing haptens (class II) were precipitated. It will therefore be unnecessary to present details of tests with compounds of any of these three classes.

TABLE I

*Tests for Specific Precipitation of Anti-A Sera Mixed with Haptens of Class I II*

Serum No	Hapten	Initial concentration of hapten (micrograms per cc.)				
		1000	200	40	8	1 6
271-I	ZA <sub>2</sub>	—	—	++	+	—
239-I	ZA <sub>2</sub>	—	+w	++	+	—
271-I	SA <sub>2</sub>	—	—	—	—	—
239-I	SA <sub>2</sub>	—	—	—	—	—
271-I	DA <sub>2</sub>	—	—	—	—	—
239 I	DA <sub>2</sub>	—	—	—	—	—

— means no precipitation, +w means very slight precipitation, + means definite precipitation, ++ means marked precipitate formation

TABLE II

*Tests for Specific Precipitation of Anti-A Sera Mixed with Haptens of Class IV B*

Serum No	Hapten	Initial concentration of hapten (micrograms per cc.)				
		1000	200	40	8	1 6
243-I	PA <sub>3</sub>	—	—	—	—	—
271-I	PA <sub>3</sub>	—	—	—	—	—
239-I	PC <sub>3</sub> A <sub>3</sub>	—	—	—	—	—
271-I	PC <sub>3</sub> A <sub>3</sub>	—	—	—	—	—
271-I	PH <sub>3</sub> A <sub>3</sub>	—	—	±	—	—
271-I	PP <sub>3</sub> A <sub>3</sub>	—	±	+±	+w	—
243-I	PA <sub>6</sub>	—	—	—	±	—
271-I	PA <sub>6</sub>	—	—	—	+	—

± means doubtful formation of precipitate. Other symbols as in Table I.

The results of tests with compounds of class III are shown in Table I. It may be seen that only one (ZA<sub>2</sub>) of these divalent haptens gave any precipitate.

Of compounds of class IVB, a number were specifically precipitable by anti-A sera, in a way which was seen to depend definitely on their constitution, but not in the way demanded by the "alternation" theory.

The results obtained with compounds of class IVB are shown in Table II. (It will be recalled that class IVA (carboxy compounds) was entirely negative) Of the haptens shown in Table II, two were negative, one gave a very weak reaction, another a slight positive reaction, and only one precipitated well. All the compounds which failed to precipitate were retested with other anti-A sera, with the same results, and compounds which did precipitate were tested with other anti A sera and with unrelated antisera to control the specificity of the reactions. These results are not shown here.

#### DISCUSSION

It is apparent from Tables I and II, and the results obtained with compounds of classes I and IVA, that predictions based on the alternation theory are by no means regularly fulfilled. No carboxy compound was ever observed to precipitate, and many of the arsonic haptens, even those containing three reactive groups, adequately separated, failed to precipitate. In all, six divalent haptens, four trivalent, and one hexavalent, failed to precipitate. These compounds nevertheless reacted with the appropriate antibodies, as was shown by inhibition experiments. It seems clear that the possibility of "lattice" (framework) formation is by no means sufficient to insure that a hapten will precipitate. As a matter of fact, a careful examination of Table II discloses a different sort of correlation between constitution and precipitability which probably provides a much more valid basis on which to predict the behavior of haptens.

It may be assumed that all the arsonic acid groups in the first four haptens shown in Table II are capable of combining with molecules of antibody, and calculations of the size of antibody molecules and the relative distances in these hapten molecules support this idea. This combination blocks off the solubilizing action which the arsonic acid groups are known to exert, and at the same time at least one, possibly several, polar groups of the antibody are combined with. The result is a complex of one hapten and three antibody molecules, which being larger than one antibody molecule, demands at least three times, perhaps more, the number of solubilizing polar groups which would just suffice to keep an antibody molecule in solution. From what is known of protein chemistry, we may surmise that this latter number probably lies somewhere between 5 and 40. In hapten PA<sub>3</sub>, three outer<sup>2</sup> hydroxyl groups still remain uncombined with, and in PC<sub>3</sub>A<sub>3</sub> there are in addition three carboxyl groups. This, in addition to the polar groups remaining free on the antibody molecules, evidently is sufficient to keep the complex in solution, for no precipitate is formed. The importance of solubilizing groups in immune reactions has been commented on by Eagle (6) who observed that the introduction of a

<sup>2</sup> The inner hydroxyls, *i.e.*, those on the phloroglucinol residue, are probably too completely blocked off mechanically (by steric hindrance) to have their full solubilizing effect.

few soluble groups into the antitoxin molecule rendered it incapable of flocculating toxin, although it could still combine

If the size of the hapten, and at the same time its non-polar character, are increased by the addition of three phenyl groups, as in hapten  $PP_3A_3$ , the result is so insoluble that the three free hydroxyl groups are no longer sufficient, and the compound is precipitable. If the size is similarly increased, but the polar character kept approximately the same by the introduction of three new hydroxyl groups, as in hapten  $PH_3A_3$ , the resulting hapten does not precipitate, or precipitates only slightly.

From spatial considerations, it is doubtful if all six of the reactive groups in hapten  $PA_6$  can simultaneously combine with antibody molecules, but it is

TABLE III

*Tests for Specific Precipitation of Acetylated (a) and Benzoylated (b) Derivatives of Compounds of Class IV B*

Serum No	Hapten	Initial concentration of hapten (micrograms per cc.)				
		1000	200	40	8	1 6
271-I	$PA_{3a}$	—?	+	±	—	—
271-I	$PA_{3b}$	—	—	±	+	—
271-I	$PC_3A_{3a}$	—	—	+w	—	—
271-II	$PC_3A_{3a}$	—	—	+w	—	—
271-I	$PC_3A_{3b}$	—	—	—	±	—
271-I	$PA_{6a}$	—	—	++	+	±
271-I	$PA_{6b}$	—	—	+w	++	+

Symbols as in Tables I and II

probable that more than three are capable of doing so, leaving less than three solubilizing groups in addition to the hydroxyls. It is therefore not surprising that this compound precipitates, although it will be noted that its precipitability is much inferior to that of  $PP_3A_3$  (or of  $ZA_2$  or VII). It is probable that a mechanism proposed by Hooker and Boyd (11), namely, mechanical occlusion of polar solubilizing groups of neighboring antibody molecules, also comes into play in this instance, and perhaps in the above cases too.

If the above explanation were correct, we should expect that acetylating or benzoylating the unprecipitable class IV haptens, so as to block off the solubilizing hydroxyls, would render them specifically precipitable. That this is so is shown by Table III, which gives the results of tests on acetylated and benzoylated derivatives of some of the compounds of Table II.

It is of considerable interest that the precipitability of the acetylated or benzoylated  $PC_3A_3$  is very slight, which may doubtless be attributed to the

three carboxyl groups still remaining. In fact the precipitability of  $PC_3A_3a$  and  $PC_3A_3b$  is quite comparable with that of the unmodified  $PA_3$  (Table II). Similarly benzoylation of hapten  $NA_3$ , which in addition to the two hydroxyls has two sulfonic acid groups, did not render it precipitable.

The relation of structure to precipitability in these compounds seems quite clear, and the possibility of "lattice" formation is evidently quite irrelevant, even if we grant the unproven assumption that the anti-A antibody is divalent. How may we explain the results obtained with divalent haptens of class III, shown in Table I, where one compound precipitated, whereas two did not, although few if any additional solubilizing groups are present?

It seems probable that the explanation of these results again rests upon the mechanical occlusion of polar groups of the neighboring antibody molecules, which in hapten  $ZA_3$  would be brought quite close together, whereas in haptens  $SA_3$  and  $DA_3$  they would be farther separated, so that all their polar groups, with the exception of those actually concerned in combining with the arsonic acid groups, would remain free to keep the complex in solution. If this suggestion is correct, the idea of Pauling, Campbell, and Pressman, that the smaller hapten molecules cannot precipitate, is erroneous. Instead, the converse would seem to be true, namely, the reason haptens  $SA_3$  and  $DA_3$  do not precipitate is that they are too large (*i.e.*, their combining groups are too widely separated).

The above interpretation is strengthened by the observation that univalent haptens (class II) never precipitate, even in the case of a biggish molecule ( $NAb$ ) having no free polar groups in addition to the arsonic acid group through which combination is effected. Evidently the reduction in free polar groups of the antibody molecule which follows this combination is by itself insufficient to reduce the solubility significantly, in the absence of mechanical hindrance due to the near by presence of another molecule of antibody.

It is not easy to say precisely how these considerations apply to the precipitation of the divalent haptens studied by Landsteiner and van der Scheer (12), such as resorcinol-disazo-*p*-suberanilic acid. At first sight, it might seem that in this hapten the two reactive groups are quite separated. However, the antisera used in these experiments were rather specific for the various anilic acids made from fatty acids of various lengths, which may indicate that the antibody when reacting with this hapten combined not only with the carboxy group but with the whole side chain right up to the resorcinol residue, which would bring the two molecules of antibody in rather close apposition. Only two solubilizing groups, the two hydroxyls of the resorcinol, then remain, and they may be somewhat hindered by the presence of the antibody molecules. Our present knowledge of the numbers of polar groups required to keep such complexes in solution does not seem sufficient to enable us to say whether this would account for the precipitability. That it may is suggested by the ex-

planation offered by Landsteiner and van der Scheer themselves, which was in terms of peculiarities in constitution such as the long aliphatic chains, which would be fairly insoluble. The observation that these compounds precipitated better after their solutions had been allowed to stand, however, unlike the compounds studied by Pauling, Campbell, and Pressman, and by myself, suggests, as Landsteiner and van der Scheer pointed out, the possibility that this happen might be somewhat aggregated in solution, giving particles possessing several combining groups, and large enough to combine simultaneously with several molecules of antibody.

The failure of any of the carboxy compounds to precipitate with anti-C sera rests undoubtedly upon the poor flocculating quality of these sera. Although they gave good reactions by the interfacial ("ring") technique, these sera, even when fresh, flocculated only slowly with casein coupled with diazotized *p*-amino-benzoic acid. (I have previously observed that the carboxy group does not have nearly the antigenic power of the arsonic acid group.) The precipitation of the arsenic-containing haptens was observed to be relatively slow compared to the flocculation of casein-arsanilic compounds by the same sera, in which case it was practically instantaneous. It is therefore not surprising that the much less "avid" anti-C antibodies could not effect precipitation of the carboxy haptens, all of which would be much less precipitable than conjugated protein antigens. Failure to take account of such facts seems to be another way in which the alternation theory is an oversimplification of the true mechanism.<sup>3</sup>

Finally we must discuss the failure of compound V to precipitate, when hapten VII, apparently so similar, precipitated readily. We can hardly avoid mention of this fact on the basis of the report of Pauling, Campbell, and Pressman that V did precipitate, for the discrepancy may possibly depend upon the differences in the antibodies in their sera and in mine, in which case it is unknown how the compounds studied here would have reacted with their sera. There is no doubt that V did not precipitate in my hands, it was tested against both bleedings of each of the five anti-A sera prepared, while these sera were still fresh and capable of precipitating hapten VII powerfully. In not a single one of these mixtures, no matter what the concentration of V, was the faintest trace of precipitation or clouding observed.

It seems likely that the failure of V to precipitate is due to the fact that the

<sup>3</sup> The test of the theory carried out by Hooker and Boyd (11) therefore seems to have been a fair test, within the framework of the hypothesis itself. It is rather interesting to consider, however, that if their sera had been sufficiently "avid," comparable to the anti-A sera studied here (assuming such anti-C sera can be made), Hooker and Boyd might have observed precipitate formation with the shorter of their haptens. Since the interpretation which they would have put on this result would probably have been the erroneous one that the alternation theory is perfectly correct, it is perhaps fortunate that this did not happen.



combining groups are insufficiently separated for more than two molecules of antibody to be able to combine simultaneously with the molecule, so that there are always free three hydroxyls and one arsonic acid group, which are sufficient to keep the complex soluble. In addition, the polar groups of the antibody molecules not concerned in the combination, might remain relatively free, as the antibody molecules would not be forced into intimate enough contact. In VII, the combining groups, being more widely separated, are probably all three able to combine simultaneously with antibody molecules. This leaves no arsonic acid groups free, and probably results in a good deal of steric hindrance of polar groups on the antibody molecules.

It is thus seen that the possibility of "framework" formation is by no means sufficient to insure specific precipitation, for although this possibility does not exist with hapten V if the above interpretation of the behavior of V is correct, it does exist in the case of haptens  $PA_3$  and  $PC_3A_3$  which did not precipitate, and hapten  $PH_3A_3$ , which gave only a trace of precipitate. Conversely, the possibility of framework formation does not seem to be necessary for precipitation, for hapten  $ZA_3$  precipitated readily, which it could not do by framework formation unless the valence of antibody is more than two, which there is some reason to doubt, both on experimental grounds, and on the basis of theories of antibody formation (15, 2, 5, 16). It is true that Pauling has described a possible mechanism for the formation of trivalent antibody, but this seems to the present author to have been introduced chiefly for the purpose of accounting for the precipitation of divalent haptens, and to have no great plausibility, even from the point of view of Pauling's own theory. There is no experimental evidence for it.

In considering the bearing of these experiments on the "alternation" theory, we should keep clearly separated in our minds two aspects of this theory. The first is the clearly implied claim of its proponents that the possibility of framework ("lattice") formation is necessary and sufficient for the initiation of a serological reaction ("aggregation would occur regardless of the affinity of the groupings for water" (7)). The second is the claim that larger aggregates are formed solely by the specific linkage of antibody groups with antigen groups. It seems to the present author that the experiments reported here completely disprove the first claim of the alternation theory. On the other hand, it is clear that if antibody is always divalent, these experiments do not bear particularly on the second claim.<sup>4</sup> I do not wish to be understood as denying that the alternation theory, in making this second claim, may be entirely justified. Indeed, evidence indicating that in certain cases the formation of larger aggregates is a phenomenon of a certain degree of specificity (19, 20) is difficult to explain, on the basis of present knowledge, unless we assume some such mechanism.

<sup>4</sup> The precipitability of the divalent hapten  $ZA_3$  would appear to demand trivalent antibody.

The question would seem to depend ultimately on whether antibody molecules have in general more than one combining group, and the evidence now available is not sufficient to settle this point

As an explanation of the *cause* of precipitation, it would seem that neither the alternation nor the Bordet theory is adequate. The alternation theory seems to be simply incorrect, and the Bordet theory too vague to account for the very definite facts presented here. For the theory suggested above (which is probably not original with me<sup>5</sup>), namely, that precipitation is due to lowering of solubility by neutralization of polar groups of antibody and hapten (or antigen) and concomitant steric hindrance of other polar groups of neighboring antibody molecules in the complex, I wish to propose the name, occlusion theory.

It will be noted that the occlusion theory simply attempts to explain why combination of antibody and antigen or hapten produces, in certain cases, a compound having too low a solubility to remain in solution. Nothing is said about the mechanism by which these primary aggregates unite with each other to build up the larger aggregates which are observed to form during serological precipitation. I shall for the present make no attempt to provide a detailed hypothetical mechanism for this, any more than I propose to explain how the aggregates are formed which result when a protein is salted out of solution by ammonium sulfate. If antibody has more than one combining group, it may well be that in specific precipitation the primary aggregates unite in a way very similar to that demanded by the alternation theory, indeed, it is hard to see how such unions could fail to play a prominent rôle in the formation of larger aggregates. It must be remembered, however, that "apparently decisive evidence" (8) has been offered that under some circumstances aggregates can be built up by a non-specific mechanism not involving "framework" formation (1, 9, 4).

If antibody were trivalent, it would certainly seem that all the divalent and trivalent haptens studied here should have been able to form frameworks, and this would be true with the trivalent haptens even if antibody were only divalent. Also divalent antibody ought to be able to build up with divalent haptens long chain-like aggregates showing pronounced birefringence of flow (Pauling), but this has not been observed (11). Until more experimental evidence is available, the multivalency (including divalency) of antibody remains almost purely a postulate. In any case, the present communication attempts simply to present evidence which seems to throw light on the reason for the tendency of primary aggregates not to remain in solution, a reason which seems to have been overlooked by the proponents of the alternation theory.

#### SUMMARY

A study of the precipitability by the appropriate antisera of 34 different haptens, containing from one to six reactive groups, leads to the conclusion that

<sup>5</sup> Compare Marrack (13), p. 150

the possibility of framework ("lattice") formation is neither necessary nor sufficient for specific precipitation, but that instead precipitation depends upon the reduction, by mutual neutralization of polar groups of antibody and antigen (or hapten) and mechanical blocking off of polar groups of closely neighboring molecules of antibody, of the solubility of the complex below the point at which it can remain in solution. The decisive factors appear to be the number of polar groups of the antigen (hapten) left free, and the distance separating the different reactive groups, which determines the amount of steric hindrance exerted by one antibody molecule on another. No hypothesis is offered as to how these primary insoluble aggregates unite with each other to produce the larger aggregates which are finally observed.

## BIBLIOGRAPHY

- 1 Abramson H. A., *Nature* 1935, 135, 995
- 2 Alexander, J., *Protoplasma*, 1932, 14, 286
- 3 Bordet J., *Traité de l'immunité*, Paris: Masson et Cie, 1920
- 4 Boyd W. C., and Hooker S. B. *Proc Soc Exp Biol and Med*, 1938 39, 491
- 5 Breinl F. and Haurowitz F. *Z physiol Chem*, 1930, 192, 45
- 6 Eagle, H., *J Exp Med* 1938, 67, 495
- 7 Heidelberger M., and Kendall F. E. *J Exp Med*, 1935 61, 563
- 8 Hershey A. D. *J Immunol.*, 1941, 42, 455
- 9 Hooker S. B., and Boyd, W. C. *J Immunol.*, 1937 33, 337
- 10 Hooker, S. B., and Boyd, W. C., *Proc 3rd Internat Cong Microbiol.*, New York, 1940
- 11 Hooker S. B., and Boyd W. C. *J Immunol.*, 1941 42, 419
- 12 Landsteiner, K., and van der Scheer J., *J Exp Med*, 1932 56, 399
- 13 Marrack, J., *The chemistry of antigens and antibodies*, London: His Majesty's Stationery Office 1934.
- 14 Morgan G. T. and Walton, E., *J Chem Soc* 1931 615
- 15 Mudd, S. *J Immunol.*, 1932 23, 423
- 16 Pauling, L., *J Am Chem. Soc.*, 1940, 62, 2643
- 17 Pauling L., Campbell, D. H., and Pressman D., *Proc Nat Acad Sc.*, 1941 27, 125
- 18 Saunders, K. H., *The aromatic diazo-compounds and their technical applications*, London: Edward Arnold and Co., 1936.
- 19 Topley, W. W. C., Wilson J., and Duncan, J. T., *Brit J Exp Path.* 1935, 16, 116
- 20 Wiener A. S., and Herman, M., *J Immunol.*, 1939, 36, 255



## THE RÔLE OF THE COMPONENTS OF COMPLEMENT IN SPECIFIC IMMUNE FIXATION\*

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Although it is known that complement combines with most antigen antibody compounds, the rôle of the components of complement in this union is not clearly understood.

It is generally stated that the mid piece of complement is the combining component (1, 2). On the other hand, Brin states that the end-piece alone is fixed (3). Others assert that both the end piece and mid piece combine with antigen antibody compounds (4-7). Deissler (8) contends that the fourth component of complement is utilized in complement fixation. Some workers claim to have confirmed this statement (9, 10), while others contradict it (11).

The present authors, in experiments preliminary to those reported in this paper, found indications that the fourth component and end piece, as well as mid piece in a smaller proportion, combine with antigen-antibody compounds.

There are several reasons for the various views of others. (1) With the exception of a few recent studies, investigations on the rôle of the complement components in fixation were performed before the discovery of the fourth component of complement. (2) Uniform methods for the preparation and identification of the individual complement components were not employed. (3) Much of the past work was qualitative in nature with little consideration of the physical and chemical conditions which affect the combination of complement with antigen-antibody aggregates. (4) The results obtained under one set of experimental conditions were frequently interpreted to fit all other conditions.

The need for more rigidly controlled studies on complement fixation is evident, and accordingly the present paper is concerned first with the conditions governing the fixation of the components of complement, and second with the identification of those components of complement which combine with specific antigen-antibody compounds.

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*Résumé of the Nature of the Components of Complement*

To assist in the interpretation of the data presented in this paper, a review of the existing knowledge of the constitution of complement is necessary. A more detailed discussion has been presented elsewhere (12)

Complement can be separated into two thermolabile components (destroyed by heating at 56° for 30 minutes) by treatment of serum with carbon dioxide-saturated water or dilute HCl, or by dialysis against distilled water (1). Accompanying each of these fractions are varying amounts of two relatively thermostable components of complement, the third and fourth components. The fraction of fresh serum insoluble in a tenfold dilution of carbon dioxide-saturated water has been termed the "globulin fraction" or the "mid-piece," while the fraction soluble in the same medium has been termed the "albumin fraction" or "end-piece." The terms mid- and end-piece were formulated by the early investigators because they supposed that the carbon dioxide-insoluble fraction had first to combine with the sensitized red blood cells before the albumin fraction would act. It is also known that either cobra venom or yeast cells destroys a relatively heat-stable component (inactivated by heating at 66°C for 30 minutes) which has been termed the third component (1). It is usually associated with the globulin fraction of serum, although, as will be shown below, it is also nearly always present in the end-piece. Pillemer and Ecker (13), investigating the nature of the yeast inactivation of the third component, isolated an insoluble fraction from yeast which adsorbs the third component specifically from fresh serum. Certain unpublished data are indicative of a lipid nature of this component (14). A fourth component of complement, inactivated by dilute ammonia, has also been discovered (1). It is usually associated with the end-piece, but, as will be shown below, under certain experimental conditions it also is often present in the mid-piece fraction of complement. Pillemer, Seifter, and Ecker (15) postulated that this component contains a reactive carbonyl group and is associated with a globulin fraction present in the so called albumin fraction.

Pillemer, Ecker, Oncley, and Cohn (16) have prepared in a highly pure state, and characterized, three of the components of complement. The mid-piece was found to be a euglobulin with an apparent isoelectric point of about 5.2. It has an electrophoretic mobility of  $2.9 \times 10^{-5}$  in a phosphate buffer of an ionic strength of 0.20 at pH 7.7, and a sedimentation constant of  $6.4 \times 10^{-13}$  in KCl of ionic strength of 0.20. It comprises only 0.60 per cent of the total serum protein, and each cubic centimeter of serum contains 0.060 mg of mid-piece nitrogen. The end-piece and fourth component were found in the same serum fraction, which was characterized as a muco-euglobulin with an apparent isoelectric point of 6.3-6.4, and with an electrophoretic mobility of  $4.2 \times 10^{-5}$ . It contains 10.3 per cent carbohydrate, and it comprises less than 0.2 per cent of the total serum protein, thus accounting for 0.02 mg of nitrogen per cc. of serum.

Pillemer and Ecker (17) on the basis of electrophoretic and functional studies, and Heidelberger (18, 22) have proposed a new nomenclature for the complement components. The symbols C'1, C'2, C'3, and C'4, which correspond to the mid-piece, end-piece, third component, and fourth component respectively in the older termi-

nology, were adopted. In the present paper the terms mid-piece and  $\text{CO}_2$ -insoluble fraction are used interchangeably as are end-piece and  $\text{CO}_2$ -soluble fraction, and the symbols C'1 and C'2 represent the mid piece and end-piece components *per se*. The terms third and fourth components are used interchangeably with the symbols C'3 and C'4 respectively.

### Materials

**Complement**—The blood of normal guinea pigs which had been maintained on a high vitamin C diet was placed in the ice box for about one hour. At the end of this time the serum was separated by centrifugation and immediately used in the experiments. In the protocols which follow the serum, unless otherwise noted, was never allowed to stand more than one hour before use in fixation experiments.

**Antigens**—Type III pneumococcus specific carbohydrate was used in the larger part of the experimental work. A stock solution of 0.1 per cent SHI<sup>1</sup> in 0.9 per cent saline was diluted with 0.9 per cent saline to the desired concentration.

Human serum, hemocyanin (from *Busycon canaliculata*) tobacco mosaic virus and red blood cells of various species were also employed as antigens.<sup>2</sup> The amounts employed are indicated in the protocols.

**Antisera**—A refined anti Type III pneumococcus rabbit serum containing 4.57 mg of antibody nitrogen per cc. was kindly furnished by the Lederle Laboratories, Inc. It was not anticomplementary in twice the quantities employed in the present experiments.

Antihuman rabbit serum, antihemocyanin rabbit serum, antitobacco mosaic virus (rabbit) serum, and rabbit antisera to red blood cells of sheep, dog, guinea pig and man were also employed. Since the latter sera were found to be somewhat anticomplementary in the amounts necessary for optimum fixation the procedure advocated by Sachs (19) was employed to remove the objectionable substances from them. This was successfully accomplished without much loss of the fixative powers of the antisera.

**Chemicals**—All chemicals used were either best grade Eastman or Merck's blue label chemicals. Unless otherwise noted, all dilutions were made with 0.9 per cent NaCl. The insoluble carbohydrate from yeast used in the removal of C'3 was prepared by the method of Pillemer and Ecker (13).

### Methods

**General Method for Fixation**—To A cc. of antiserum, B cc. of undiluted fresh serum were added with thorough mixing. The mixture was then brought to the desired temperature, tonicity and hydrogen ion concentration. C cc. of antigen adjusted to the desired experimental conditions, were then added rapidly with constant stirring.

<sup>1</sup> S with the appropriate numeral is used for the type-specific polysaccharide of the pneumococcus.

<sup>2</sup> We are indebted to Dr. M. Heidelberger for a generous supply of anti Type III pneumococcus rabbit serum, to Dr. S. B. Hooker for hemocyanin and antihemocyanin rabbit serum and to Dr. W. M. Stanley for crystalline tobacco mosaic virus.

The mixture was allowed to stand for the prescribed time at the required temperature. Following this incubation the mixture was centrifuged for 30 minutes at 2750 R.P.M., and the clear supernatant was drawn off carefully with a pipette, adjusted to the required conditions, and finally made up with 0.9 per cent NaCl to a 10 per cent dilution of the original guinea pig serum. This solution was tested for hemolytic activity, and if found not to show more than 10 per cent of its original activity it was further tested for content of individual complement components.

*Complement Titration*—A unit of complement, designated as producing 100 per cent hemolysis, was considered to be the smallest amount of a 10 per cent dilution of untreated serum which caused complete hemolysis of 1 cc. of 2.5 per cent suspension of sheep red blood corpuscles containing 5 units of antiserum per cc. An identical amount was employed in all reactivations and complement component determinations.

*Estimation of the Individual Component Activity in Fixed Complements*—A unit of the complement rendered inactive by fixation was added to an equal amount of each of the specifically inactivated complement components described below. The mixture was incubated at room temperature for 15 minutes, 1 cc. of sensitized sheep red cell suspension added, and the hemolytic titer read after 30 minutes of incubation at 37.5°C. The amount of hemolysis produced was estimated by comparison with a series of standard hemoglobin solutions, and expressed as percentage of complete hemolysis.

It is pointed out that the data presented in this paper do not indicate the absolute quantity of each component present, but only represent the residual activity present after fixation or specific inactivation.

For the further clarification of the data, the per cent hemolysis resulting from the inter-reactivations of the "specifically inactivated complements" (see below) is included in each protocol.

Success in the reactivations depends largely on preventing the loss of activity of the complement components which might occur during the course of an experiment. Therefore, all serum reagents should be kept at 0°C ( $\pm 1^\circ$ ) until they are to be used. Precautions of this kind are necessary for obtaining comparable, reproducible data. Furthermore, slight deviations from any technique described here may alter the end-result of an experiment.

In the interpretation of data on hemolysis no significance is attached to differences of 10 per cent hemolysis or less, because of the proscribed limit of accuracy of the method.

### *The Preparation of Complements Deprived of Various Components*

These are hereafter designated "specifically inactivated complements"

1 Complement was deprived of active C'4 by appropriate treatment of serum with hydrazine or ammonia (15, 20)

2 Complement was deprived of C'3 by treatment of serum with zymine or the insoluble carbohydrate prepared from fresh yeast (13)

3 Complement was deprived of C'1 and C'2 activity by heating serum at 56°C for 30 minutes



4. The  $\text{CO}_2$ -soluble and  $\text{CO}_2$ -insoluble fractions were prepared by saturation of diluted serum with  $\text{CO}_2$  as described elsewhere (12). While this method results in the sharp separation of C'1 and C'2 from one another, marked variation occurs in the distribution of C'3 and C'4 in the fractions. The  $\text{CO}_2$ -soluble fraction or end piece, contains all of the active C'2, usually from 70 to 100 per cent of the C'4, and from 20 to 40 per cent of the C'3. The  $\text{CO}_2$ -insoluble fraction, or mid-piece, contains all of the C'1, usually about 60 to 80 per cent of C'3, and from 0 to 30 per cent of the C'4. In this laboratory it is believed that the residual C'4 manifest in the mid piece is accompanied by a small amount of C'2, since it is the opinion here that C'2 and C'4 are associated in the same guinea pig serum protein constituent.

#### EXPERIMENTAL

*Factors Which Influence the Fixation of the Components of Complement*—In these experiments complement fixation was carried out with anti Type III pneumococcus rabbit serum compounds

##### 1 *The Effect of Aging of Complement*—

A pool of fresh guinea pig serum was divided into two portions, one of which was allowed to incubate for one hour with the specific antipneumococcus complexes, at the end of which time the fixability of the complement components was determined. The second portion of serum was allowed to stand for 19 hours in the ice box (5 C.) and was tested in a like manner. The serum lost 50 per cent of its complementary activity during the 19 hours in the cold. Complete hemolysis was brought about by 0.07 cc. of 10 per cent dilution of fresh serum while 0.14 cc. of 10 per cent dilution of aged serum was required.

The results of this experiment, performed in quintuplicate, are tabulated in Table I. An inspection of the data shows that when serum stood for 19 hours and lost 50 per cent of its complementary activity the following changes in the fixability of the complement components occurred: (a) C'4 became more resistant to fixation, (b) C'3 underwent no change in fixability, (c) there was less reactivation upon the addition of the  $\text{CO}_2$ -insoluble fraction, and increased reactivation upon the addition of the  $\text{CO}_2$ -soluble fraction in the case of the aged serum.

Most investigators have allowed complement to age or "cure" in an ice chest overnight before using it in fixation experiments (18, 21), however, it is apparent from the data presented here that this procedure may lead to serious error in the determination of the fixability of the various components of complement. In this laboratory, therefore, it is the practice to allow serum complement to stand not more than one hour before use in fixation experiments.

2 *The Effect of Time of Incubation*—An experiment was performed to determine the optimum time necessary for the fixation of the various components of complement.

The reagents were mixed as described in the section of this paper dealing with the general method of fixation, and were allowed to stand at 25°C for different periods of time. At the end of the allotted time the residual complement component activities were determined. In order to avoid occlusions and uneven distribution of reagents, separate tubes were employed for each incubation.

TABLE I  
*The Effect of Aging on the Fixation of Complement*

1:8 pneumo- coccic anti- serum	Guinea pig serum	1:40 000 SIII	Hemolysis produced by supernatant after fixation		Hemolysis produced after addition of specifically inactivated complements									
					Serum treated with hydrazine		Serum treated with insoluble carbohy- drate		Serum heated at 56°C for 30 mins.		CO <sub>2</sub> - insoluble fraction (“mid piece”)		CO <sub>2</sub> -soluble fraction (“end piece”)	
			I*	II†	I	II	I	II	I	II	I	II	I	II
cc	cc	cc	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
0.2	1	0.2	0	0	0	25	50	55	10	5	65	40	20	35
0.2	1	0.2	0	0	0	25	60	60	Tr	5	65	40	15	30
0.2	1	0.2	0	0	0	25	50	60	10	Tr	65	40	15	25
0.2	1	0.2	0	0	0	25	50	60	10	Tr	65	40	15	25
0.2	1	0.2	0	0	0	30	60	50	15	Tr	65	45	15	30

Specifically inactivated complements	Hemolysis													
	I	II												
	per cent	per cent												
Serum treated with hydrazine	0	0	—	—	80	60	80	90	40	60	90	90		
Serum treated with in- soluble carbohydrate	0	0	80	60	—	—	60	35	60	60	40	25		
Serum heated at 56°C for 30 mins.	0	0	80	90	60	35	—	—	0	0	0	0		
“End-piece”	0	0	90	90	40	25	0	0	85	90	—	—		
“Mid-piece”	0	0	60	40	60	50	0	0	—	—	85	90		

\* I, fresh sera.

† II, sera after standing 19 hours at 5°C

The results of this experiment show that C'4 was fixed in the first 5 minutes of incubation and remained fixed for the duration of the 80 minute incubation. Maximum fixation of mid-piece occurred after 40 minutes of incubation, while little or no variation in the fixation of end-piece occurred that could be attributed to the effect of time of incubation. On the basis of these data an incubation time of 60 minutes was chosen as the optimum time to be used in the remaining fixation experiments.

3 *The Effect of Temperature*—Although earlier workers (23, 24) determined the optimum temperature for the fixation of complement (considered as a single entity), no knowledge exists concerning the influence of temperature on the fixation of the individual components of complement. The results of an experiment performed to determine the effect of temperature on the fixation of the individual components reveal that maximum fixation of all the com-

TABLE II

*The Effect of Varying Hydrogen Ion Concentration on the Fixation of Complement*

pH*	Relative quantity and appearance of precipitate	Hemolysis produced by supernatant after fixation	Hemolysis produced after addition of specifically inactivated complements				
			Serum treated with hydrazine	Serum treated with symin	Serum heated at 56°C. for 30 mins.	CO <sub>2</sub> -soluble fraction ("end-piece")	CO <sub>2</sub> -insoluble fraction ("mid-piece")
		per cent	per cent	per cent	per cent	per cent	per cent
5.3	++++ plaque	0	15	15	20	50	0
6.1	+++ plaque	0	15	20	20	45	0
7.0	++ granular	0	0	60	0	35	0
7.1	++ granular	0	0	40	0	15	0
8.1	++ granular	0	0	50	0	25	0
8.8	++ plaque	0	0	50	0	25	0
Specifically inactivated complements		Hemolysis					
		per cent					
Serum treated with hydrazine.		0	—	70	90	90	0
Serum treated with symin.		0	70	—	80	25	60
Serum heated at 56 C. for 30 mins.		0	90	80	—	0	0
"End piece"		0	90	25	0	—	85
"Mid-piece"		0	0	60	0	85	—

\* 1 cc. of guinea pig serum was fixed by the aggregate from 0.2 cc. of 1:4 antipneumococcus rabbit serum and 0.2 cc. of 1:10,000 SIII. All reagents were made up to volume with phosphate buffers of ionic strength 0.15. The pH indicated here is the pH of the supernatants after fixation.

ponents occurred at 22°C. Although slight differences in the fixability of the components were evident at 0° and 22°, marked differences occurred as between these temperatures and 37°C. At the latter temperature C<sub>4</sub> was more resistant to fixation. On the basis of these data further fixation experiments were conducted at temperatures between 20 and 25°C.

4 *The Effect of Hydrogen Ion Concentration*—The results of an experiment to determine the effect of hydrogen ion concentration on the fixation of the individual complement components are shown in Table II.

In this experiment all reagents were either diluted or made up to volume with phosphate buffers of various hydrogen ion concentrations and of ionic strength 0.15. The complement was incubated with the antigen-antibody complexes for one hour at a temperature of 23°C. Before determination of their complement component activities the supernatants were adjusted to a neutral pH with 0.1 N HCl or 0.1 N NaOH.

Table II shows the following: (a) at pH's below 7.0, less fixation of C'4 and C'1 occurred than at pH 7.0, but there was an enhancement of the fixation of C'3, (b) at pH's above 7.0 up to 8.8 there occurred complete fixation of C'4 together with an increased fixation of C'1, and (c) optimum fixation of the components of complement occurred at neutral pH's.

In this experiment the CO<sub>2</sub>-insoluble fraction contained no C'4, and no reactivation resulted upon the addition of CO<sub>2</sub>-insoluble fraction to complement rendered inactive by fixation. This demonstrates that C'2 was bound along with C'4. If, however, C'4 is present in the CO<sub>2</sub>-insoluble fraction, reactivation by the latter of fixed sera in which no C'4 and C'2 can be demonstrated, is due to the presence of small amounts of C'2 in the CO<sub>2</sub>-insoluble fraction.

Another point of interest evident from the experiment is that complementary activity was removed by specific aggregates over an extremely wide pH range, although there was marked variation in the fixation of the individual components at different pH's. On the basis of these data all other fixation experiments were conducted at pH's between 7.0-7.2.

5 *The Effect of Tonicity*—Although the effect of varying salt concentration on the fixation of complement is well known (21), nothing is known of the effect of variations of tonicity on the fixation of the individual complement components. The results of an experiment performed to determine this effect revealed the following: (a) complement in slightly hypertonic NaCl solutions was fixed incompletely, and (b) complement in hypotonic NaCl solutions was fixed completely with little or no variation in the fixation of the individual components.

CaCl<sub>2</sub> is known to interfere with complementary activity (1), and is further known to interfere with certain adsorption reactions (25). An experiment performed to show the effect of CaCl<sub>2</sub> on the fixation of the components revealed the following points: (a) in amounts over 0.2 per cent, CaCl<sub>2</sub> interfered with the fixation of C'4 and C'1, and (b) in all amounts used CaCl<sub>2</sub> did not influence the fixation of C'3.

6 *The Effect of Propionaldehyde*—Pillemer, Seifter, and Ecker (15) have shown that propionaldehyde protects the fourth component from inactivation by hydrazine. Since the direct and immediate inactivation of complement by specific aggregates appears to involve C'4, experiments were performed to determine if propionaldehyde would interfere with the fixation of the components. The results of such an experiment are given in Table III. It is seen

that propionaldehyde in amounts far greater than that needed to oppose the anti C'4 effect of hydrazine failed to inhibit the fixation of complement. However, slightly less C'4 was fixed in the presence of propionaldehyde, while there was no interference with the fixation of the other components.

7 *The Effect of Dilution of Complement*—Table IV summarizes the results of an experiment undertaken to determine the fixability of the components of complement which had been diluted previous to fixation. The table shows

TABLE III  
*The Effect of Propionaldehyde on the Fixation of Complement*

1:8 parumo- coccic anti- serum	Guinea pig serum	0.16 molar propional- dehyde	0.9 per cent saline	1:40 000 SIII	Hemol- ysis pro- duced by super- natant	Hemolysis produced by supernatants after addition of specifically inactivated complements				
						Serum treated with hydrazine	Serum treated with insoluble carbohy- drate	Serum heated at 56°C. for 30 mins.	CO- soluble fraction ("end- piece")	CO- insoluble fraction ("mid- piece")
cc.	cc.	cc.	cc.	cc.	per cent	per cent	per cent	per cent	per cent	per cent
0.2	1	1	0	0.2	0	10	50	10	15	55
0.2	1	0.5	0.5	0.2	0	10	50	10	10	60
0.2	1	0.25	0.75	0.2	0	5	60	10	15	70
0.2	1	0.125	0.87	0.2	0	10	60	Tr	10	65
0.2	1	0	1	0.2	0	0	60	Tr	10	65

Specifically inactivated complements	Hemol- ysis					
	per cent					
Serum treated with hydrazine....	0	—	80	80	90	40
Serum treated with insoluble carbohydrate	0	80	—	60	40	60
Serum heated at 56 C. for 30 mins.	0	80	60	—	0	0
"End-piece"	0	90	40	0	—	85
"Mid-piece"	0	60	60	0	85	—

that (a) the fixation of C'4 was inhibited only in very large dilution, and (b) there was an increase of fixation of the mid-piece and end piece on dilution.

8 *The Effect of Varying Amounts of Complement*—The results of an experiment performed to determine the variations which occur in the fixation of the complement components when increasing amounts of complement are added to a standard amount of antigen antibody aggregate, show that increasing amounts of complement resulted in a slight increase in the fixation of C'4, a marked decrease in the fixation of C'1, and little or no variation in the fixation of C'3.

9 *The Effect of Varying Amounts of Antigen and Antibody*—The results of

an experiment dealing with the effects of varying amounts of antigen and antibody on complement fixation, show the following (a) in extreme excess of antigen or antibody the fixation of complement or its individual components was markedly inhibited, (b) when very dilute solutions of antigen and antibody were used C'4 did not fix completely, (c) a slight excess of antibody resulted in maximum fixation of the combining components of complement. Therefore, in the experiments reported here, antibody was employed in a slight excess

TABLE IV  
*The Effect of Dilution on the Fixation of Complement*

1:8 pneumococcal antiserum	Guinea pig serum	1:40,000 SIII	0.9 per cent sodium chloride solution	Relative quantity and appearance of the precipitate	Hemolysis produced by supernatant after fixation	Hemolysis produced after addition of specifically inactivated complements				
						Serum treated with hydrazine	Serum treated with insoluble carbohydrate	Serum heated at 56°C for 30 mins.	CO <sub>2</sub> -soluble fraction ('end-piece')	CO <sub>2</sub> -insoluble fraction ('mid-piece')
cc	cc	cc	cc		per cent	per cent	per cent	per cent	per cent	per cent
0.2	1	0.2	0	++ gran	0	0	60	0	50	70
0.2	1	0.2	1	++ gran	0	0	50	0	30	50
0.2	1	0.2	2	+ gran	0	0	45	0	20	30
0.2	1	0.2	3	+ gran	0	0	45	0	20	30
0.2	1	0.2	4	±	0	0	50	0	20	Tr
0.2	1	0.2	5	0	0	20	60	0	20	Tr
Specifically inactivated complements					Hemolysis					
					per cent					
Serum treated with hydrazine					0	—	60	70	95	50
Serum treated with insoluble carbohydrate					0	60	—	60	35	90
Serum heated at 56°C for 30 mins					0	70	60	—	0	0
"End piece"					0	90	35	0	—	95
"Mid-piece"					0	50	90	0	95	—

*The Fixation of Normal Guinea Pig Complement and Specifically Inactivated Guinea Pig Complement*—In order to determine whether the removal of one or more components of complement interferes with the fixation of the remaining components, an experiment such as the one summarized in Table V was carried out. In this experiment normal complement and specifically inactivated complements were added to the specific aggregates of Type III pneumococcus specific substance. The table reveals the following points: (1) Almost all of C'4, 25 per cent of C'3, 75 per cent of C'1, and nearly all of C'2 were removed or inactivated during fixation of normal complement. This is at variance with

the assumption of most workers that the mid piece is the single combining component, as all of the components were fixed in varying amounts under the conditions of the experiment (2) Inactivation of C'4 by hydrazine or the

TABLE V

*The Fixation of Normal and Specifically Inactivated Guinea Pig Complements*

Paramecium antiserum 1:8	1:40,000 SIII	1 cc. of various serums or serum fractions	Hemolysis after fixation	Hemolysis produced after addition of specifically inactivated complements					
				Serum treated with hydrazine	Serum treated with insoluble carbohydrate	Serum heated at 56°C. for 30 mins.	Serum treated with hydrazine and insoluble carbohydrate	"End piece"	"Mid. piece"
n	cc.		per cent	per cent	per cent	per cent	per cent	per cent	per cent
0.2	0.2	Guinea pig serum	0	5	65	10	10	20	Tr
0.2	0.2	Serum treated with hydrazine	0	0	80	0	0	Tr	0
0.2	0.2	Serum treated with insoluble carbohydrate	0	10	Tr	0	0	0	0
0.2	0.2	Serum treated with hydrazine and insoluble carbohydrate	0	0	10	0	0	0	0
0.2	0.2	Serum heated at 56 C. for 30 mins.	0	95	90	0	75	0	0
0.2	0.2	End piece	0	95	40	0	40	0	45
0.2	0.2	Mid piece	0	0	40	0	0	0	0
Specifically inactivated complements			Hemolysis						
			per cent						
Serum treated with hydrazine.			0	0	65	90	0	95	0
Serum treated with insoluble carbohydrate			0	65	0	90	10	45	60
Serum treated with insoluble carbohydrate and hydrazine			0	0	10	60	0	25	0
Serum heated at 56 C. 30 mins.			0	90	90	0	60	0	0
End piece			0	90	45	0	25	0	90
"Mid piece"			0	0	60	0	0	90	0

removal of C'3 by the insoluble carbohydrate from yeast did not markedly influence the fixation of the other components. (3) The inactivation of both C'1 and C'2 by heat inhibited the fixation of C'4 and C'3 (4) When end piece, which contained C'2, C'4, and a small amount of C'3 was added to the specific aggregates, no fixation of C'3 and C'4, and partial inactivation of C'2 resulted. Although, C'1 is fixed in the absence of C'4, functionally in so far

as hemolysis is concerned, it is inactive. In studies on the mechanism of immune hemolysis (26), it will be shown that unless C'4 is either fixed previously to or simultaneously with C'1, no hemolytic activity occurs. (5) All of C'1 but only a small amount of C'3 were removed in the fixation of mid-piece which contained all of C'1 and the major portion of C'3.

The results of many experiments similar to the one above show that the direct and immediate inactivation of complement which occurs in fixation is due to the fixation of almost all of C'4 and C'2 and of a part of C'1. C'3 does not appear to play a major part in such fixation reactions. However, it appears that the inactivation of the thermostable components (C'4 and C'3) does not interfere with the fixation of the thermolabile components (C'1 and C'2). Further, in the absence of mid-piece, C'2 and C'4 are not adsorbed or inactivated by fixation, while in the absence of C'2 and C'4, C'1 is still adsorbed by specific aggregates. The full significance of these results will be elaborated in a subsequent paper dealing with immune hemolysis since they are best interpreted when a visible reaction, such as hemolysis, occurs.

*The Fixation of the Components by Complement by Various Antigen-Antibody Systems*—In order to determine whether the nature of the antigen influences the fixability of the components of complement, a series of experiments was conducted in which antigens of different characteristics and molecular sizes were used.

The components of complement were fixed quite similarly by human serum-antihuman rabbit serum, tobacco mosaic virus-antitobacco mosaic virus rabbit serum, and by hemocyanin-antihemocyanin rabbit serum aggregates. The fixation of the components by these systems was qualitatively similar to fixation by SIII-antipneumococcus Type III rabbit serum (Table V).

Since sensitized red blood cells of different species are commonly employed in the assay of complementary activity, an experiment was performed in which complement was allowed to fix to the specific aggregates of sheep, dog, human, and guinea pig erythrocytes at 1° C. The results obtained were similar to those described for other aggregates, except for a few minor deviations. Whereas the fixation of C'4-C'2 in these cases was almost identical with their fixation by other systems, C'3 appeared not to be adsorbed at all. Marked variations occurred in the amounts of C'1 which combined with the different red blood cell aggregates, as expressed in the following order: guinea pig > sheep > human > dog.

#### DISCUSSION AND SUMMARY

From the experiments reported here it is evident that the amount of each complement component which combines with specific immune aggregates depends upon a number of factors, including the age of the complement, the concentrations of antigen, antibody, and complement, hydrogen ion and electrolyte concentrations, and time and temperature of incubation for fixation.



The experiments also reveal the following

1 C'4 must be considered a combining component of complement because it is invariably inactivated or adsorbed by specific aggregates.

2 C'3, although necessary for the final action of complement, e.g., hemolysis or bactericidal action, is fixed only partially or not at all by antigen antibody compounds.

3 C'2 is fixed together with C'4, as is evident from those experiments in which reactivations were conducted with a CO<sub>2</sub>-insoluble fraction which contained no C'4 activity

4 Mid piece, which contains C'1, generally stated to be the single combining component of complement, is adsorbed by immune aggregates in varying amounts depending on the experimental conditions employed

5 No inactivation or adsorption of C'4 and of C'3 occurs upon the addition to specific aggregates of serum which has been heated at 56°C for 30 to 50 minutes. This indicates that certain thermolabile constituents of serum are necessary for the fixation of C'4. Inactivation of C'4 by hydrazine or the removal of C'3 by the insoluble carbohydrate from yeast does not markedly influence the fixation of the other components

6 The assumption that the mid piece is the single combining component of complement is further questioned for the following reasons

First, C'4 in fresh, untreated serum combines with specific aggregates, but C'4 in heat inactivated serum does not. It is, therefore, apparent that a part of the combining complement must be attributed to C'4 and its carrier C'2. Second, it will be shown in a subsequent paper that C'1, heated at 56°C for 45 minutes, combines with specific immune complexes, and in doing so may in fact inhibit the further combination of the components of untreated complement. This effect, first noted by Ehrlich and Sachs (27), is termed a "complementoid" action. Thirdly, it will also be shown on the basis of quantitative nitrogen data (28), that the combining nitrogen, in those instances in which large amounts of serum are added to a constant amount of aggregate, should for the most part be attributed to C'4 and its carrier C'2

7 The nature and the molecular size of the antigen does not influence the qualitative picture of fixation of the complement components.

8 While it is tempting to speculate on the mechanism of complement fixation, it probably is advisable that such speculation be postponed until experiments similar to those reported here are performed with purified components. However, certain differences between the fixation of the complement components to specific aggregates and the adsorption of these components to non-specific agents, are apparent. For example, in specific immune fixation C'4, C'2, and varying amounts of C'1 are fixed, while in non-specific adsorption both to inorganic adsorbents (29) and to untreated bacteria (30, 31), no fixation of C'4-C'2 occurs while all of the other components of complement are adsorbed. Furthermore, C'3 is bound only partially or not at all to specific

aggregates, while it is completely adsorbed or inactivated by non-specific adsorbents. It appears, therefore, that the highly reactive component, C'4, is directly and immediately involved in specific immune fixation.

9 A very small amount of specific immune aggregate combines with a large amount of complement, whereas a large amount of non-specific agent adsorbs only a small amount of complement. This difference is undoubtedly due to the marked chemical affinity of C'4-C'2 and C'1 for the surfaces presented by immune aggregates.

10 It can be now stated that when complement exerts its activity in hemolytic, bacteriolytic, or bactericidal reactions, C'4-C'2 and varying amounts of C'1 must first combine (fix) with the antigen-antibody compound in question, and that any secondary manifestation is dependent both on the adjunctive action of the unbound C'3 (26) and on the nature of the substrate employed.

The chemical and immunological implications of these results will be further elaborated in subsequent papers.

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#### BIBLIOGRAPHY

- 1 Osborne, T. W. B., *Complement or alexin*, London, Oxford University Press, 1937.
- 2 Zinsser, H., Enders, J. F., and Fothergill, L. D., *Immunity Principles and applications in medicine and public health*, New York, The Macmillan Company, 5th edition, 1939.
- 3 Brin, S. M., *Z. Immunitätsforsch.*, 1927, 51, 392.
- 4 Smith, H., *Brit. Med. J.*, 1910, 2, 1433.
- 5 Skwirsky, P., *Z. Immunitätsforsch.*, 1910, 5, 538.
- 6 Browning, C. H., and Mackie, T. J., *Immuno-chemical studies*, London, Constable & Co., 1925.
- 7 Dean, H. R., *J. Hyg.*, Cambridge, Eng., 1912, 12, 259.
- 8 Deissler, K., *Z. Immunitätsforsch.*, 1932, 73, 365.
- 9 Misawa, T., Ohta, T., and Imahori, H., *Z. Immunitätsforsch.*, 1936, 86, 505.
- 10 Bier, O. J., *Z. Immunitätsforsch.*, 1936, 89, 218.
- 11 Ueno, S., *Japan J. Med. Sc., VII Social Med. and Hyg.*, 1938, 2, 201, 225.
- 12 Ecker, E. E., and Pillemer, L., *Ann. New York Acad. Sc.*, in press.
- 13 Pillemer, L., and Ecker, E. E., *J. Biol. Chem.*, 1941, 137, 139.
- 14 Pillemer, L., Seifter, S., and Ecker, E. E., unpublished data.
- 15 Pillemer, L., Seifter, J., and Ecker, E. E., *J. Immunol.*, 1941, 40, 89.
- 16 Pillemer, L., Ecker, E. E., Oncley, J. L., and Cohn, E. J., *J. Exp. Med.*, 1941, 74, 297.
- 17 Pillemer, L., and Ecker, E. E., *Science*, 1941, 94, 437.
- 18 Heidelberger, M., *J. Exp. Med.*, 1941, 73, 681.
- 19 Sachs, H., *Berl. klin. Woch.*, 1921, 58, 1075.
- 20 Gordon, J., Whitehead, H. R., and Wormald, A., *Biochem. J.*, 1926, 20, 1028, 1036, 1044.

- 21 Eagle, H., Laboratory diagnosis of syphilis St. Louis The C. V. Mosby Company, 1937
- 22 Heidelberger, M., Weil, H. A., and Treffers, H. P., *J. Exp. Med.* 1941, 73, 695
- 23 Dean, H. R., *J. Path. and Bact.*, 1917, 21, 193
- 24 Matsumoto, I., *J. Chosen Med. Assn.* 1935, 25, 699
- 25 Eagle, H., and Brewer, G., *J. Gen. Physiol.*, 1929, 12, 845
- 26 Pillemer, L., Seifter, S., Chu, Fey, and Ecker, E. E., to be published.
- 27 Ehrlich, P., and Sachs, H., *Berl. klin. Woch.* 1902, 39, 297, 335, 492
- 28 Pillemer, L., Chu, Fey, Seifter, S., and Ecker, E. E., to be published.
- 29 Ecker, E. E., Jones, C. B., and Kuehn, A. O., *J. Immunol.*, 1941, 40, 81
- 30 Gordon, J., and Thompson, F. C., *Brit. J. Exp. Path.*, 1935, 16, 101
- 31 Ecker, E. E., Weisberger, A., and Pillemer, L., unpublished data.



## STUDIES ON MENINGOCOCCAL INFECTION

### XII IMMUNOCHEMICAL STUDIES ON MENINGOCOCCUS TYPE II

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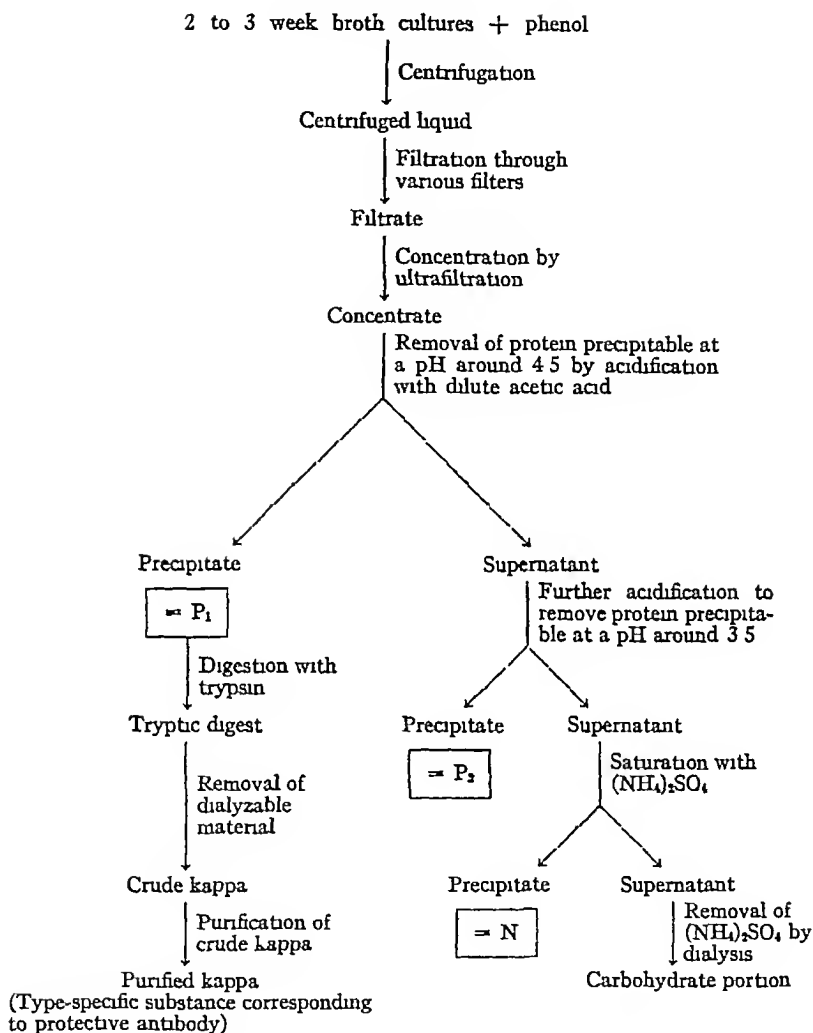
Rake and Scherp (1, 2) have isolated from broth autolysates of meningococcus group I III three principal fractions, one of protein nature and two of carbohydrate nature. They have demonstrated that the former carries group-specific properties while of the latter, one has type-specific and the other group-specific properties. Little was known about the immunochemistry of Type II meningococcus when the present work was initiated. Rake and Scherp (1, 2) had isolated from this type a group-specific protein component and demonstrated that type-specific properties were connected with a certain fraction, which gave both carbohydrate and protein reactions.

The present work was undertaken to further our knowledge of Type II meningococcus, it was carried out for the most part on a virulent Type II strain (Herrington), and comprised (a) studies on autolysates from cultures grown in hormone broth and (b) studies on young cultures grown on blood agar.

#### *Studies of Broth Autolysates*

Broth autolysates were obtained as described previously (1, 2). After phenol to 0.5 per cent had been added they were centrifuged at 30,000 to 35,000 R.P.M. in a Sharples supercentrifuge, and the supernates filtered through various filters to clarify and to remove bacterial debris. Final filtration was always carried out through Chamberland L5 filters. The filtrates were concentrated by ultrafiltration through Bronfenbrenner alundum candles (3) coated with 7 per cent collodion in glacial acetic acid. The concentrates were "washed" on the membrane with distilled water until the filtrates were Molisch negative. The filtrates were discarded, as they were found to be serologically inactive. 5 filtrates of the 7 different preparations having been tested.

The dark brown colored concentrates may be fractionated as shown in the flow sheet. The  $P_1$  precipitates were further purified by repeated solution in slightly alkalinized water, followed by precipitation with dilute acetic acid, until the supernates had become Molisch negative. These steps were carried out in the cold. The water washed precipitates were either dried from frozen state

*Flow Sheet*

on a cryochem apparatus (4) or further washed with acetone, filtered, and dried *in vacuo*

Chemical properties of P<sub>1</sub> fractions obtained from 7 different preparations are summarized in Table I. These substances are gray or brown, insoluble in distilled water or saline, but soluble on addition of minimum amounts of dilute NaOH to brown solutions, which flocculate with dilute acetic acid or Tanret's reagent and give positive biuret, Millon, and Sakaguchi reactions.

In one instance a similar substance was obtained by acidifying the super-

centrifugate directly. This latter method was not used more frequently, however, as ultrafiltration removed broth constituents which otherwise might precipitate together with  $P_1$ .

As exemplified in the flow sheet, further portions of protein nature (Tanret and biuret positive) can be separated from the supernates of  $P_1$ . Type specificity was found to be present not only in  $P_1$ , but also in both  $P_2$  and  $N$ . Data concerning  $P_2$  and  $N$  are included in Tables II and V. These data, which will be clarified in connection with the experiments described for component  $P_1$ , show that  $P_1$  was considerably richer in type-specific substance than  $P_2$  and somewhat richer than  $N$  (Table V),  $N$  being antigenically less homogeneous than  $P_1$  (Table II).

The deproteinized mother liquors contain portions of carbohydrate nature. Only very weak type-specific serological reactions were given by these polysac-

TABLE I

*Extremes and Mean Values of Chemical Properties of  $P_1$  Fractions Isolated from Various Preparations of the Herrington Strain of Type II Meningococci*

	Yield per liter of broth	pH of maxi- mum precipita- bility	Job	N	P	Carbo- hydrate	Ash as Ca
	mg.			per cent	per cent	per cent	per cent
Highest value	234.2	3.9	-58	14.6	0.9	3.2	0.24
Lowest value	93.0	4.7	-38	13.1	Trace	1.8	0.15
Mean	162	4.4	-46	13.7	0.4	2.8	0.2

\* The method of Heidelberger and Kendall (5) was applied and the colors, read in a photo-electric colorimeter, evaluated from equations calculated from galactose standards.

charides when present in high concentrations. Carbohydrate fractions were, however, reactive with polyvalent antimeningococcus horse sera, known to contain antibodies for the group-specific C fraction, and they also showed some reactivity with polyvalent Type 4-8 antipneumococcus horse sera. Such fractions contained about 35 to 37 per cent hexosamine. As peptone was a constituent of the medium it seems reasonable to assume that such portions contain chiefly blood group A substance (from peptone (6)) together with meningococcus C substance and mere traces of type-specific material.

For these reasons  $P_2$ ,  $N$ , and carbohydrate components were studied less thoroughly.

### Serological Studies

For serological studies the ring test technique was applied throughout, the readings recorded in the tables are those taken after 2 hours at 37°.

The following antimeningococcus Type II sera were used: (1) A pool from several

bleedings of two rabbits designated 13-15, these animals had been immunized with whole cultures of Type II meningococcus and the mouse protective value of this pool was 67 units (2) Another pool, also from several bleedings of two rabbits and designated 3185-3192, exhibited 180 mouse protective units For certain tests the latter serum was exhaustively absorbed with young Type I organisms grown on blood agar, and was then designated "3185-3192 absorbed." (3) Three more sera (M18, M22, and M37) were prepared by immunizing rabbits with 6 hour cultures of Type II meningococci The mouse protective values of these three sera were 16, 47, and 27 units respectively (4) Similarly, anti- $P_1$  sera were prepared by immunizing rabbits with 1:1000 saline dilutions of a  $P_1$  fraction, starting usually with 0.1 ml. and increasing the dose gradually to 1.0 ml.  $P_1$  proved to be quite toxic, as evidenced by temperature reactions and by several fatalities Anti- $P_1$  sera gave strong precipitin reactions with meningococcal proteins (*cf* Tables V and X), but were of only low mouse protective value, the highest potency observed was 9 units They reacted also with acid-precipitable protein derived from Type I (Table V) but exhibited, on the other hand, a certain degree of type specificity in the agglutination reaction

In serological respects,  $P_1$  exhibited two important properties (1) It reacted strongly with both antiprotein serum and (absorbed) antimeningococcus Type II serum 3185-3192, as will be seen from data recorded in Table V During the course of experiments attempting to separate the type-specific fraction from the protein it was found that the reactivity with antiprotein serum was lost after digestion with proteolytic enzymes while the reactivity with serum 3185-3192 was retained fully or even increased These experiments will be described in detail later (*cf* page 443, and Table V) (2) It removed from protective serum (13-15) all protective antibody Thus samples of serum 13-15 were absorbed with various  $P_1$  fractions at the antigen excess end of the equivalence zones, the absorptions were carried out by keeping the mixtures in the cold and shaking occasionally for 4 days All the  $P_1$  fractions from Type II removed all protective antibody, a protein component derived from Type I and comparable to  $P_1$  in so far as it was acid-precipitable and prepared in an analogous manner, failed to do so The data of these experiments are recorded in Table II

As mentioned above, we have reason to believe that  $P_1$  is richer in type-specific substance than either  $P_2$  or N Accordingly, attempts were made to separate the type-specific principle from  $P_1$  protein However, contrary to the experiences with Type I meningococcus (1, 2, 7), we could not separate the type-specific substance from protein by repeated acid precipitation The following methods also failed to separate type specificity from "accompanying" protein (a) treatment with  $\text{CHCl}_3$  and butyl alcohol, according to Sevag (8), at neutrality and at slight alkalinity, (b) heating  $P_1$  in diluted  $\text{Na}_2\text{CO}_3$  solution at 50 to 55°C, followed by neutralization and repeated treatment with  $\text{CHCl}_3$  and butyl alcohol, according to Sevag, Lackman, and Smolens (9), (c) subfractionation with the aid of  $(\text{NH}_4)_2\text{SO}_4$ , (d) electrophoresis in a 7 cell electrophoresis apparatus (10)



a Saline solutions of a  $P_1$  preparation ( $BIT^{10}P_1$ ) were treated with  $CHCl_3$  and butyl alcohol. The aqueous phases were tested serologically. Protein removal was paralleled by loss of all serological reactivity.

TABLE II

*Precipitin Reaction of Various Fractions with Serum 13-15 (67 Mouse Protective Units) and Mouse Protective Units Remaining in the Serum after Absorption*

		Reactivity of absorbed serum with fraction used for absorption and with unabsorbed serum									
		$BIT^{10}P_1$	13-15	$BIT^{10}P_1$	13-15	$BIT^{10}P_1$	13-15	$BIT^{10}N$	13-15	$BIT^{10}N$	13-15
Serum absorbed with equal volume of saline dilution 1	100	±	+++	-	+++	-	++	++	(-)	-	-
	250	+	±	(±)	++	(-)	±	++	(-)	-	±
	500	±	+	+	±	(-)	(±)	+++	(-)	(-)	±
	750	++	(±)	±	(±)	±	(-)			(-)	(±)
	1000	+++	(-)	±	+	±	-			(±)	(-)
Serum absorbed with equal volume of dilution 1		200		300		200		100		600	
Mouse protective units in absorbed serum		<5**		<10**		<4**		<5**		56	

\* In this and the following tables the following denotations are used

(-) questionable reactions.

(±) very weak but still definite reactions.

± weak but definite reactions.

++

+++ = increasing amounts of precipitate.

++++

++++±

+++++

† Laboratory designation of  $P_1$  fraction used.

‡ Laboratory designation of N fraction.

§ Laboratory designation of acid-precipitable protein component prepared from Type I, the dilutions used in this instance were 1 300 600 900 and 1200 respectively

\*\* Least value tested.

b About 100 mg of a  $P_1$  preparation ( $BIT^{10}P_1$ ) were treated under the conditions described by Sevag, Lackman, and Smolens (9). Aliquots were withdrawn before and in the course of  $CHCl_3$  treatment and tested serologically, as recorded in Table III. From the combined  $CHCl_3$  layers a substance was isolated by addition of redistilled acetone. This substance was of protein nature, as evidenced by its preparation and by its being biuret positive. It was tested before and after tryptic treatment with antiprotein serum and with

TABLE III

*P<sub>1</sub> Treated According to Sewag, Lackman, and Smolens (9) Parallelism of Protein Removal with Decrease of Serological Reactivity*

Conditions	No of treat-ments	Vs antiprotein serum M2-1.5.39			Vs 3185-3192 absorbed		
		1T	5T	10T	1T	5T	10T
Untreated		++++			+++		
Heated at 50 to 55°C in diluted Na <sub>2</sub> CO <sub>3</sub> solution	0	+++±			+++		
	2	+++			+		
	4	++			(±)		
	6	+±			(∓)		
	8	+			—		
	10	+			—		
	12	±			—		
	14	±			±		
Tryptic digested after 14 treat-ments*	14	(±)			±		
Substance isolated from CHCl <sub>3</sub> phase							
Before trypsin		+++±	+++	++	+	±	—
After trypsin		±	—	—	+++	++	+±

\* Dilution 1 2.5T

TABLE IV

*Cell Contents after 21 Hours Electrophoresis of P<sub>1</sub> and Serological Tests on Them*

Cell No	1 (Cath- odic)	2	3	4		5	6		7	
Appearance	Water clear color less	Water clear color less	Water clear color less	Water-clear supernate over flocculent precipitate		Water clear color- less	Slightly turbid		Slight flocculent precipitate	
				Super- nate	Redis- solved pre- cipi- tate		Super- nate	Redis- solved pre- cipi- tate	Super- nate	Redis- solved pre- cipi- tate
Biuret	—	—	—	±	+++	—	—	—	—	+
pH	9.6	8.0	6.8	6.2		5.9	5.5		3.6	
Vs antiprotein serum M2-12 14 38	—	—	—	—	+++± (±)*	—	—	—	—	++ —*
Vs serum 3185-3192 ab- sorbed	—	—	—	—	+± +++*	—	—	—	—	(±) +*

\* After digestion with trypsin.

absorbed 3185-3192 serum, as recorded in Table III. This experiment shows again that the active principle is firmly bound to protein, as it disappeared gradually from the aqueous phase and could be found in the protein portion isolated from the  $\text{CHCl}_3$  layer.

c 820 mg of a  $P_1$  preparation ( $\text{BII}^{\text{P}}P_1$ ) were fractionated with  $(\text{NH}_4)_2\text{SO}_4$ . Three fractions of protein nature were obtained, precipitable at 23 per cent, 45 per cent, and 100 per cent saturation in yields of 317, 143, and 130 mg respectively. These fractions gave positive biuret and Sakaguchi reactions. Only the portion precipitable at 23 per cent saturation gave a distinct Millon test. All three were reactive with both antiprotein serum and with absorbed 3185-3192 serum, and all three removed nearly all protective antibody from serum 13-15 (67 units). From the final  $(\text{NH}_4)_2\text{SO}_4$  supernates a small, serologically inactive, biuret negative, and strongly Molisch positive fraction (64 mg) was obtained. This experiment also shows that the active principle is connected with protein.

d A dialyzed solution of 40 mg of a  $P_1$  preparation ( $\text{BII}^{\text{P}}P_1$ ) in 20 ml distilled water was subjected to electrophoresis in a 7 cell apparatus (10) at 2,000 volts. The substance was placed in the middle cell, the other cells being filled with distilled water. After electrophoresis for 21 hours, the picture, including biuret and serological tests, was as recorded in Table IV. This experiment shows that, on electrophoresis, partial migration and separation take place, but that serological reactivity again is only connected with those portions which also are biuret positive, i.e., only with components of protein nature. Two more electrophoresis experiments on another  $P_1$  fraction ( $\text{BII}^{\text{P}}P_1$ ) and on a  $P_2$  fraction (see flow sheet) led to the same conclusions.

#### *Action of Enzymes on $P_1$ —Kappa Substance*

Under the influence of proteolytic enzymes  $P_1$  loses its reactivity with anti- $P_1$  serum, while its reactivity with (absorbed) antimeningococcus Type II serum is fully retained or even intensified, as exemplified by the following experiment.

Two 10 ml. samples of an aqueous solution of a  $P_1$  fraction ( $\text{BII}^{\text{P}}P_1$ ) containing 159 mg. per 15 ml. were pipetted into Wassermann tubes. To each sample 10 ml.  $\alpha/5$  phosphate buffer pH 7.0 and 2 drops of toluene were added. To one of the tubes 0.25 ml. of a trypsin solution (250 mg./10 ml.) which had been roughly purified by removing acid precipitable material, was added. The tubes were capped and placed into a water bath at 37° for 4 days. Saline dilutions corresponding to 1:1000, 1:5000, and 1:10,000 of the substance originally used were made up and tested against anti- $P_1$  serum and against absorbed 3185-3192 serum.

All of the  $P_1$  fractions were tested according to this general scheme. The mean results are recorded in Table V. Trypsin controls which had been incu-

bated in absence of  $P_1$ , reacted neither with anti- $P_1$  serum nor with absorbed 3185-3192 serum

The results of numerous other enzymatic experiments (Table V) may be summarized as follows (a) Serial addition of trypsin up to 2 ml trypsin (i.e. 50 mg) per 10 mg  $P_1$  and incubation up to 10 days did not alter the results in any way (b) Identical results were obtained when tryptic digestion was

TABLE V

*Reactivity of Meningococcus-Protein Fractions with Antisera Protein Serum and with Absorbed Antisera meningococcus Type II Serum*

Laboratory designation of fraction	Enzyme	$V_s$ antiprotein serum						$V_s$ anti Type II serum, absorbed					
		Before enzyme			After enzyme			Before enzyme			After enzyme		
		1T	5T	10T	1T	5T	10T	1T	5T	10T	1T	5T	10T
$P_1$ (Mean of 7 preparations)*	Commercial trypsin†	+++±	++±	++(±)	+(±)	±	-	+++±	+(±)	+	+++±	++(±)	±±
$BII^uP_1$	Activated papain at neutral reaction‡				++	++±	+				+++±		±±
$BII^uP_1$	Crystalline pepsin at pH 3.0				±	-	-				+++±	++±	++
$BI^uP_1$ **	Commercial trypsin	+++±		±±	(±)	-	-	-	-	-	-	-	-
		500	5T	10T	500	5T	10T	500	5T	10T	500	5T	10T
$BII^uP_1$	Commercial trypsin	+++±	++		+	±		++	-		+++±	-	
$BII^uN$	Commercial trypsin	+++±	±	±	++	±	±	+++±	+	±	+++±	+	±

\* Similar results on  $P_1$  from a culture grown on a semisynthetic medium, containing casein-hydrolysate and yeast extract as principal ingredients

† Similar results when digested at pH 7.6, 8.5, or in  $N/4$   $Na_2CO_3$ . Similar results with crystalline trypsin, crystalline chymotrypsin, or mixtures of both at neutral reaction

‡ Similar results on three other fractions digested at pH 5.2

|| Similar results when digested in  $N/10$  HCl

\*\* Acid precipitable protein component prepared from Type I

carried out in saline solution or at pH values of 7.6 or 8.5 or in  $N/4$   $Na_2CO_3$  solution (c) Activated papain at neutral reaction and at pH 5.2 caused essentially the same effect, although the destruction of anti- $P_1$  serum reactivity was less marked (d) Crystalline pepsin acted at pH 3.0 and in  $N/10$  HCl solutions essentially the same way as trypsin at the conditions described

It appeared evident that the type-specific principle could not be removed from protein by mild, simple, and but slightly destructive means. As, however, this principle was found in enzymatic digests of  $P_1$ , we attempted to iso-

late this substance, termed kappa substance, from tryptic digests. By purifying tryptic digests with charcoal, followed by dialysis,<sup>1</sup> fairly colorless kappa was obtained (cf Table VI), as, however, by repeated charcoal treatment eventually all serological reactivity was lost, the following method of purification was chosen

P<sub>1</sub> from 4 different preparations was pooled and digested with trypsin in presence of phosphate buffer pH 7.5. The digest was freed from phosphate by dialysis and brought to dryness on a cryochem apparatus. 1.8 gm. of crude kappa substance were obtained from 9.4 gm. P<sub>1</sub>. On the basis of the precipitin

TABLE VI

*Chemical and Serological Properties of Crude Kappa, Purified Kappa, and of Component 1 Separated from Crude Kappa by (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Fractionation*

	[α] <sub>D</sub>	N	P	Carbo- hydrate	Serological reactivity with						
					Anti-protein serum			3185-3192, absorbed			
					1T	10T	100T	1T	10T	100T	1M
		per cent	per cent	per cent							
Crude kappa		9.0	1.5	8.9	+	(±)	—	++++	+++	+	
Purified kappa		9.6	1.4	12.3	(=)	—	—		++++	±	(=)
		9.6		12.9	(±)	—			++++	±	—
Main component of the (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> su- pernatant	+7.5	8.7	1.7	7.8	—	—	—	+±	(=)	—	
	+13.5	8.1		7.0	(=)	—	—	+	—	—	
	+14.1	6.8			—	—		+	—		
Kappa obtained by charcoal treatment	+2	5.2			+±	—		++++	+++	±	

test there was approximately a tenfold increase in activity from P<sub>1</sub> to crude kappa.

Such crude kappa substance was further purified by removal of a small portion, insoluble in chilled 0.2 M acetate buffer pH 4.0, followed by (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> fractionation.<sup>2</sup> At 62.5 per cent (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> concentration, the bulk of active material flocculated out. Material isolated from the supernatant showed very

<sup>1</sup> 250 mg. trypsin autodigested in presence of phosphate buffer and dialyzed against distilled water yielded after drying from frozen state a residue too small to be collected. This small residue dissolved only partially in 0.2 M acetate buffer at pH 4.0, the clear centrifuged supernatant rendering only a faint opalescence on saturation to 62.5 per cent with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>. Trypsin may therefore be excluded as tangible impurity in any of our kappa preparations.

<sup>2</sup> (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> being removed subsequently by dialysis.

little serological reactivity The portion precipitable at 62.5 per cent  $(\text{NH}_4)_2\text{SO}_4$  was repeatedly treated with  $\text{CHCl}_3$  and butyl alcohol, according to Sevag (8), when only a small amount of material was removed into the  $\text{CHCl}_3$  phase The aqueous phase was brought to dryness on a cryochem apparatus The yield was 172 mg purified kappa from 727 mg crude kappa In addition, 169 mg "almost inactive" material from the  $(\text{NH}_4)_2\text{SO}_4$  supernates, and (active) minor fractions, aggregating to 93 mg, were isolated, the  $\text{CHCl}_3$  phase rendered 10 mg of (active) material In another experiment, 177 mg purified kappa were obtained from 545 mg crude kappa On the basis of the precipitin test, there was only little increase in serological activity from crude kappa to purified kappa

Purified kappa consists of a grayish brown powder, readily soluble in distilled water or saline to give a somewhat opalescent solution, which clears up on addition of minimal amounts of diluted  $\text{NaOH}$  It is Tanret, Sakaguchi, and ninhydrin-positive but biuret-negative Chemical and serological properties are recorded in Table VI

When tested in the precipitin reaction with three different anti-Type I sera, kappa was found non-reactive with one of these sera, while weak reactions ( $++$  and  $+$  respectively in 1:1T, and  $+$  and  $\pm$  in 1:10T) were observed in the other two sera<sup>3</sup> It is not known whether these weak reactions are due to small amounts of an impurity or to the "existence of antigenic determinants of diverse specificity" in the kappa molecule, in the sense of Hooker and Boyd's observation on systems of crystalline duck and egg albumin and their antibodies (11)

Kappa removes practically all protective antibody from Type II protective antisera, as shown in Table VII Quantitative nitrogen determinations performed according to the method of Heidelberger and Kendall (12-14) on the precipitates of these experiments, indicate a correlation between total precipitated nitrogen and mouse protective value

Electrophoresis experiments carried out both in the Tiselius apparatus,<sup>4,5</sup> and in a 7 cell apparatus (10) did not free kappa from colored matter Part of the color at least seems, nevertheless, not to be an integral part of the molecule, as supernates of serum M22 pooled-1, absorbed with kappa at the equivalence point, were distinctly brown colored, but did not react with unabsorbed serum Possibly electrophoresis in the Tiselius apparatus at other pH values might have led to separation of colored matter from kappa Lack of material

<sup>3</sup> Weak heterologous reactions of the same order of magnitude had also been observed with the mother substance of kappa,  $\epsilon$ ,  $\text{P}_1$

<sup>4</sup> We wish to express our thanks to Dr D Moore, of the Presbyterian Hospital in New York, and Dr B Chow, of this Institute, for carrying out these tests

<sup>5</sup> Kappa being dissolved in 0.02 M phosphate buffer pH 7.45 and pH 7.47 respectively

has prevented us from such studies. As the color of kappa interfered in the Tiselius apparatus with observation and photographic recording the question about the electrophoretic homogeneity of kappa remains still unanswered.

In the experiment conducted by Dr Chow, small quantities of a fast moving colored portion (a) and a slow moving, slightly colored portion (b) were collected and isolated.\* Both were equally reactive with absorbed serum 3185-3192. By further absorption of this serum with (a) all reactivity with (b) and with kappa had disappeared. When kappa was subjected to electrophoresis

TABLE VII

*Equivalence Zone Determination of Various Anti-Type II Sera with Kappa and Mouse Protective Units Remaining after Absorption at Antigen Excess End of Equivalent Zone*

Serum absorbed		M12-pooled-1 (16MPU)		M22-pooled-1 (47MPU)		M27-11.22.40 (27MPU)	
		Reactivity of absorbed serum with kappa or with unabsorbed serum					
		Kappa	M12-pooled-1	Kappa	M22-pooled-1	Kappa	M27-11.22.40
Serum absorbed with equal volume of saline dilution 1	320			(=)	++		
	500					-	+++
	640			±	-		
	1T			+++±	-	-	+±
	1.5T	(±)	+±			-	±
	2.0T	(±)	±			(±)	-
	2.5T	±	-			(±)	-
2.0 ml. serum absorbed with 1.0 ml. saline dilution of kappa 1		750		239		750	
Mouse protective units remaining in absorbed serum		4		4		3	
Mg total precipitated N <sub>2</sub> per ml. serum		0.175		0.533		0.278	

from the cathodic end-cell of the 7 cell apparatus (10) migration took place through the whole system into the anodic end-cell. After 21 hours the main portions of kappa had accumulated in the cathodic and anodic end-cells, as indicated by the color and as confirmed by weight determinations on the isolated cell contents. No serological cross reactions occurred, when samples of absorbed serum 3185-3192 were further absorbed with these main portions of kappa which had been subjected to electrophoresis, and were cross tested in

\* We must leave the question open whether kappa separated under the experimental conditions into 2 (or more) portions, or whether the appearance of a colored, fast moving, and a but slightly colored slow moving portion was due to the superimposed effect of colored matter

the precipitin reaction. The fact that electrophoresis effected no separation into serologically different fractions indicates a certain degree of purity for kappa. Neither the experiments in the Tiselius apparatus nor those in the 7 cell apparatus gave any indication of separation of serologically active carbohydrate from kappa. Carbohydrate appears to be rather in chemical linkage to the rest of the molecule. This point is supported by the fact that serum-kappa precipitates are always of the finely granular type, which usually is interpreted as a protein-antiprotein reaction, compact discs, which are considered as indicative of carbohydrate-anticarbohydrate, were never observed. Considering the various data, kappa itself appears as a protein split-product, carrying some colored matter as an impurity which can be separated only with difficulty. The protein nature of kappa is manifested by positive ninhydrin and Sakaguchi tests and is indicated by the electrophoretic mobility in the Tiselius apparatus which is in the order of  $10^{-5} \frac{\text{cm/sec}}{\text{volt/cm}}$ . Besides amino acids, there appears to be carbohydrate present as part of the molecule. The bulk of kappa, therefore, can be considered to be a carbohydrate-containing polypeptide.

### *Studies on Young Cells*

As we had isolated this kappa substance from broth autolysates, we were interested in ascertaining whether we could identify the protein from broth autolysates with protein from young meningococci Type II cultures. Five to 6 hour blood agar cultures were fractionated according to the method developed by Heidelberger and Kendall (15) on a scarlatinal strain of hemolytic streptococcus and later applied by Heidelberger and Menzel (16) in their studies on tubercle bacilli. Save for slight, unessential modifications in the procedure, methods and designations are the same in the present work. The properties of the main fractions (D and K) obtained in two different preparations are compiled in Table VIII.

These quantitatively most abundant fractions were used to absorb protective serum 13-15 in the same manner as described above. This serum contained originally 67 units. The results are recorded in Table IX.

Furthermore, the various fractions were subjected to tryptic digestion and serological tests performed as described above. The results upon D and K are recorded in Table X.

The absorption experiments show that specificity corresponding to protective antibody is predominantly connected with fraction K, although this specificity is encountered to a considerably lesser degree also in fraction D, the experiments on tryptic digested fractions show clearly a basic difference between D and K. The serological, as well as the chemical properties, of the several intermediate fractions lie broadly between those of D and K. It



TABLE VIII

Chemical and Immunological Properties of Protein Fractions D and K of Type II Meningococci

Preparation	Fraction	Yield	pH of extraction	pH at which precipitated	pH of solution used for help determination	[α] <sub>D</sub>	N	P	Carbohydrate	Basic ash as Ca
		gm.					per cent	per cent	per cent	per cent
BII <sup>6</sup>	D	1 966	7 0	3 7-3 9	6 7	+12 3	15 7	3 1	10 0	0 1
	K	0 731	$\frac{N}{10}$ NaOH	4 5-5 3	6 7	-45 7	13 3	0 5	2 1	0 0
BII <sup>6A</sup>	D	1 358	6 8	3 6-4 0	7 5	+27 0	16 0	3 7	11 1	0 3
	K	1 256	$\frac{N}{10}$ NaOH	4 6-4 8	6 8	-41 1	13 8	0 8	2 2	0 2

TABLE IX

Equivalence Point Determination of Various Fractions from Whole Cells with Serum 13-15, and Mouse Protective Units Remaining after Absorption at Equivalence Point

		Reactivity of absorbed serum with fraction used for absorption and with unabsorbed serum, respectively							
		BII <sup>6</sup> D	13-15	BII <sup>6</sup> D	13-15	BII <sup>6</sup> K	13-15	BII <sup>6A</sup> K	13-15
Serum absorbed with equal volume of saline dilution 1	100	+	+++	-	++ (±)	-	+++	-	+++
	250	+++	±	+++	+	-	+++	-	+++
	500	+++±	+	+++±	(±)	-	++	-	++
	750	++++	±	+++±	-	+	+	-	+
	1000	++++	±			+	±	(±)	±
	1250	++++	(±)			+	-	±	(±)
	2500	++++	-			++	-	+	-
Serum absorbed with equal volume of saline dilution 1		100		100		500		750	
Mouse protective units in absorbed serum		57		24		<5*		<4*	

\* Least value tested.

TABLE X

Reactivity of Various Fractions Derived from Young Mass Cultures before and after Tryptic Digestion

Fraction	F <sub>2</sub> anti-protein serum						V <sub>2</sub> anti-Type II serum absorbed					
	Incubated control			After trypsin			Incubated control			After trypsin		
	1T	5T	10T	1T	5T	10T	1T	5T	10T	1T	5T	10T
BII <sup>6</sup> D	+++	±	+	+	-	-	++	+	(±)	±	-	-
BII <sup>6A</sup> D	+++	++	+	(±)	-	-	+++	±	-	±	-	-
BII <sup>6</sup> K	+++±	+++	+++	++	+	+	+++±	+++	±	+++±	++	±
BII <sup>6A</sup> K	+++±	+++	++	++	+	±	+++±	+++	±	+++	+++	++

is, therefore, possible that those intermediate fractions are mixtures of "ideal" D and K. No indication of the presence of type-specific substance was found in the acid extracts of the meningococci in the precipitin test with absorbed 3185-3192 serum, the final conclusion being that specificity corresponding to protective antibody in young cells is also intimately connected with protein, especially that protein portion (K) which requires the highest alkali concentration to be brought into solution.

It seemed conceivable that by immunizing rabbits with K, sera of high protective values could be obtained. This was not the case. The highest potency ever observed in 3 animals was 8 units. Precipitins against meningococcal proteins were, however, obtained in high titer.

#### DISCUSSION

The preceding experiments show that in meningococcus Type II Herrington strain, type specificity corresponding to protective antibody is intimately connected with protein. In this respect meningococcus Type II differs strikingly from Type I and also differs from the various strains of pneumococci.

Rake and Scherp (1, 2) have isolated from Type I broth autolysates a protein component, which on account of its acid precipitability might be compared with  $P_1$  of the present studies. Both components occur uniformly in the step of acid precipitation, although neither is believed to be a chemically pure entity.  $P_1$  removes from protective anti-Type II serum all protective antibody, it is furthermore reactive with absorbed 3185-3192 serum before and after tryptic digestion, the acid-precipitable component from Type I, on the other hand, lacks all these qualities (Tables II and V).

It appears that type specificity of Type II, as manifested by correspondence to the protective antibody, is firmly connected with protein. Also in young cells type specificity occurs in connection with protein constituents, predominantly with that protein portion which requires the highest alkali concentration to effectuate dissolution.

In broth autolysates this type-specific substance appears to be connected with various components of protein nature. We have used  $P_1$  as an easily accessible starting material for isolation of this substance, although possibly other protein portions ( $P_2$  or N of the flow sheet) could be used to advantage for this purpose. The kappa substance could be split from  $P_1$  by tryptic digestion and further purified by methods described above. Although this substance has not as yet been obtained in absolutely pure state, we feel that the purity arrived at indicates that the bulk of kappa is composed of a carbohydrate-containing polypeptide. The chemical linkage of the phosphorus still remains to be ascertained.

The term "type-specific substance," is usually connected with the idea of polysaccharides, although a few examples of type specificity in connection with protein or protein-like substances are known. Such instances are well estab-

lished in Group A hemolytic streptococci (17-19, 15) and in Type A staphylococcus (20). Type specificity is completely destroyed by proteolytic enzymes in the cases of Lancefield's M substance (18, 19) and Verwey's staphylococcal protein (20). In the instance of meningococcal protein, however, this is not so. Kappa substance indeed behaves as if it constitutes an enzyme-resistant prosthetic group to meningococcal protein. For this reason, we believe that we are dealing with a new kind of type-specific substance, different from the type-specific polysaccharides and also different from the above discussed type-specific proteins.

Polysaccharidic antigens, which also contain some polypeptide as part of their molecule, are known, for instance the specific antigen obtained from *B. dysenteriae* (21). Therefore, kappa would seem to belong in the middle of a sequence of type-specific substances varying from proteins to polysaccharides as follows: (1) proteins, all specificity destroyed by enzymes, (2) proteins, type specificity connected with an enzyme-resistant prosthetic group, comprising polypeptides plus some carbohydrate, (3) polysaccharides containing some polypeptide, (4) polysaccharides, polypeptide-free. Such a scheme would find further confirmation in the fact that results somewhat analogous to ours have been obtained by Henriksen and Heidelberger by the tryptic digestion of protein fractions of the hemolytic streptococcus (22).

Our findings differ from the results of Miller and Boor (23). These investigators are of the opinion that the type-specific substance of Type II meningococcus is of lipocarbohydrate nature, comparable to the substances isolated by Borvin and Mesrobianu (24) from *B. aertrycke* and other microorganisms. This discrepancy, however, may find an explanation, in the fact that Miller and Boor have worked with strains of meningococcus Type II different from our strain.

Experiments carried out by us on strains other than the Herrington strain, namely the Albany strain 36 and two strains of Miller and Boor's, designated 44 and 45, indicated that only the Albany strain 36 resembled closely the Herrington strain, in that from it an acid-precipitable  $P_1$  could be obtained which chemically and serologically resembled  $P_1$  from the Herrington strain. Autolysate concentrates of strains 44 and 45 were reactive with both antiprotein serum and with absorbed anti-Type II serum, losing the former but retaining the latter reactivity after digestion with trypsin. Acid-precipitable portions could not be obtained from such autolysate concentrates, but on saturation with  $(\text{NH}_4)_2\text{SO}_4$  to 33.3 per cent precipitates resulted, which serologically, although not chemically, resembled the  $P_1$  fractions obtainable from Herrington strain preparations. These facts certainly indicate the presence of kappa substance also in strains 44 and 45.

#### CONCLUSIONS

From meningococcus Type II broth autolysates, a substance, corresponding to the protective antibody has been isolated. This substance, termed kappa

substance, is firmly connected with protein but can be separated by the action of proteolytic enzymes. Methods of preparation and purification are given, together with chemical and serological data. In whole cells from young cultures, this substance is also connected with protein, especially with one protein fraction which requires highest alkali concentration to effect solution.

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#### BIBLIOGRAPHY

- 1 Rake, G, and Scherp, H. W, *J Exp Med*, 1933, 58, 341, 361
- 2 Scherp, H. W, and Rake, G, *J Exp Med*, 1935, 61, 753
- 3 Bronfenbrenner, J, *J Exp Med*, 1927, 45, 873
- 4 Flosdorf, E. W, and Mudd, S, *J Immunol*, 1938, 34, 469
- 5 Heidelberger, M, and Kendall, F. E, *J Immunol*, 1936, 30, 267
- 6 Goebel, W. F, *J Exp Med*, 1938, 68, 221
- 7 Scherp, H. W, and Rake, G, *Proc Soc Exp Biol and Med*, 1934, 31, 557
- 8 Sevag, M. G, *Biochem Z*, 1934, 273, 419
- 9 Sevag, M. G, Lackman, D. B, and Smolens, J, *J Biol Chem*, 1938, 124, 425
- 10 du Vigneaud, V, Irving, G. W, Dyer, H. M, and Sealock, R. R., *J Biol Chem*, 1938, 123, 45
- 11 Hooker, S. B, and Boyd, H. C, *J Immunol*, 1934, 26, 469, 1936, 30, 41
- 12 Heidelberger, M, Sia, R. H. P, and Kendall, F. E, *J Exp Med*, 1930, 52, 477
- 13 Heidelberger, M, Kendall, F. E, and Soo Hoo, C. M, *J Exp Med*, 1933, 58, 137
- 14 Heidelberger, M, and Kendall, F. E, *J Exp Med*, 1935, 61, 559
- 15 Heidelberger, M, and Kendall, F. E, *J Exp Med*, 1931, 54, 515
- 16 Heidelberger, M, and Menzel, A. E. O, *J Biol Chem*, 1934, 104, 655
- 17 Hirst, G. K, and Lancefield, R. C, *J Exp Med*, 1939, 69, 425
- 18 Lancefield, R. C, *J Exp Med*, 1928, 47, 469
- 19 Zittle, C. A, *J Immunol*, 1939, 37, 1
- 20 Verwey, W. F, *J Exp Med*, 1940, 71, 635
- 21 Morgan, W. T. J, *Biochem J*, 1937, 31, 2003
- 22 Henriksen, S. D, and Heidelberger, M, *J Immunol*, 1941, 42, 187
- 23 Miller, C. P, and Boor, A. K, *Proc 3rd Internat Cong Microbiol*, New York, 1940, 800, and private communication.
- 24 Borvin, A., Mesrobianu, I, and Mesrobianu, L, *Compt rend Soc biol*, 1933, 114, 307. Borvin, A, and Mesrobianu, L, *Rev immunol*, 1935, 1, 553, *Compt rend Soc biol*, 1937, 124, 1176

# STUDIES ON HYPOALBUMINEMIA PRODUCED BY PROTEIN-DEFICIENT DIETS

## I. HYPOALBUMINEMIA AS A QUANTITATIVE MEASURE OF TISSUE PROTEIN DEPLETION\*

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The realization within recent years of the prevalence and seriousness of protein deficiency has emphasized the need for some simple means of recognizing the presence and degree of such a condition. The only proteins capable of direct clinical measurement are those in the blood. Yet there has, so far, been no evidence that a lowered plasma protein concentration reflects accurately anything but a deficiency in the blood alone.

During the course of other experiments, evidence was adduced indicating the existence of a constant relationship between losses in the total circulating plasma albumin and in the body protein as a whole. Thus, of course, immediately suggested a means of recognizing and evaluating total body protein deficiency. Of the plasma proteins it is only the albumin fraction which consistently decreases during an inadequate protein intake (1-3), for this reason consideration may be confined to this fraction alone. The total circulating serum albumin can be readily obtained by multiplying the albumin value by the plasma volume which may be estimated from the body weight or determined directly. By subtracting this total circulating serum albumin from the normal, the number of grams of albumin by which the serum is depleted is obtained. The depletion in the tissue protein is, of course, readily measured by determining the total nitrogen loss in the urine and feces. Now if the relationship between total serum albumin depletion and total tissue protein depletion is represented by the equation 
$$\frac{\text{Total serum albumin depletion}}{\text{Total protein depletion}}$$

=  $K$ , the value of  $K$  is readily calculated. On the other hand if  $K$  is known and the serum albumin measured the only unknown would be the tissue protein depletion for which the equation could then be solved.

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<sup>1</sup> Because fibrinogen comes out in the globulin fraction, serum albumin and plasma albumin are practically the same, the terms will be used interchangeably in this paper.

TABLE I

*Data Showing the Approximate Quantitative Relationship (K) between Dietary Changes in Total Serum Albumin and Tissue Protein*

Author	Dietary procedure	Plasma volume	Loss of serum albumin and tissue protein		
			Total albumin loss (gm.)	Total tissue protein loss (gm. total urinary N $\times$ 6.25)	K (serum albumin loss / tissue protein loss)
Weech, Goettsch, and Reeves (2)	Low protein—carrot diet 30 days	Assumed 1/20th of body weight	Not recorded	Not recorded	0.04 (approximate)
Holman, Mahoney, and Whipple (4) Dog 22-131	Glucose by gavage for 24 days	Directly determined (dye)	11.9	292*	0.04
Madden <i>et al</i> (5) Dog 39-223	Fasted 1 wk.	Directly determined (dye)	3.28	82.6	0.04
Madden <i>et al</i> (5) Dog 39-234	Fasted 1 wk.	Directly determined (dye)	5.14	101.25	0.05
Present data	Low protein diet for 21 days	Assumed 1/20th of body weight	5.28	176	0.03
Average					0.04
			Gain in serum albumin and tissue protein		
			Total albumin gain (gm.)	Total tissue protein gain (gm. N retained $\times$ 6.25)	K (serum albumin gain / tissue protein gain)
Elman, Sachar, Horvitz, and Wolf (6) average of 4 dogs	4 gm of casein hydrolysate per kg per day by mouth for 1 wk.†	Assumed 1/20th of body weight	1.76	71.87	0.02
Average of 5 dogs	4 gm of casein hydrolysate per kg per day for 1 wk. intravenously†	Assumed 1/20th of body weight	1.4	32.6	0.04

\* Loss in last 5 days estimated

† Calories supplied with karo syrup

In this paper we shall present evidence indicating that such a constant relationship between the total circulating serum albumin and the tissue proteins does exist under conditions of inadequate protein intake, and that in dogs at least the value for  $K$  is in the neighborhood of 0.04. Indeed, there are reasons for believing that the same equation applies to the distribution of nitrogen intake during replenishment of the depletion.

Although no previous studies could be found devoted to the topic of this communication data of several workers have been used in calculations which seem to confirm the thesis presented in this paper. These calculations are simple. Total serum albumin loss is obtained by multiplying the plasma volume by the change in the concentration of serum albumin nitrogen during the experimental period. The loss in tissue protein was measured by determining the total negative nitrogen balance during the same period. By comparing these two figures of nitrogen loss the proportion of total nitrogen loss was obtained which could be accounted for by the serum albumin change. When the plasma volume was not actually determined, it was assumed to be one twentieth of the body weight.

Weech, Goettsch and Reeves (2) noted that about 4 per cent of the nitrogen lost by dogs on a low protein diet could be accounted for by the decline in total circulating serum albumin. Calculations made of the data presented in the papers of Holman Mahoney and Whipple (4) and of Madden Zeldis Hengerer Miller Rowe, Turner, and Whipple (5) showed a decline in the total circulating albumin of fasted dogs which also represented about 4 per cent of the total nitrogen lost. It was interesting to note that the same percentage was reached if one calculated in the same way data obtained while regeneration of serum albumin was produced by feeding protein. During the correction by protein alimentation in experimentally induced hypoproteinemia of dogs, Elman Sachar Horvitz, and Wolf (6) found that only about 4 per cent of the nitrogen which the dogs retained could be accounted for by the increase of serum albumin thus produced. These previous observations are summarized in Table I.

#### PRESENT OBSERVATIONS

Five dogs were placed on a protein-poor diet containing karo syrup Ringer's solution and a vitamin B complex concentrate for 3 weeks. A constant intake was achieved by feeding the dogs by gavage twice daily a solution prepared as follows: 200 gm. of a vitamin B complex concentrate (labco)<sup>2</sup> and 5 000 gm. of karo syrup were made up to 10 000 cc. with 4 times concentrated Ringer's solution. Each feeding consisted of enough of this stock solution to provide 25 calories per kilo body weight *i.e.*, 12.5 cc. per kilo diluted 4 times with water and given by gavage. The total daily energy intake was therefore 50 calories per kilo.

Plasma albumin determinations and concomitant nitrogen balance studies were carried out while the dogs were on the diet described above. The chemical and experimental procedures have been described in a previous paper (6).

<sup>2</sup> Obtained from the Borden Company, Bainbridge, New York.

## EXPERIMENTAL FINDINGS

The results of the present experiments are tabulated in Table II and are really self-explanatory. In brief they show that of the total nitrogen lost by the dogs during 3 weeks on a low protein diet, a relatively small but constant percentage averaging about 3 per cent, represented the fall in serum albumin. The calculations employed were those previously described. The value found in these experiments compares fairly well with those derived from the literature as tabulated in Table I.

TABLE II

*Quantitative Relation (K) between Total Tissue Protein Loss and Serum Albumin Loss during 3 Weeks of a Protein-free Diet (Plasma Volume Assumed to be 1/20th of Body Weight)*

Dog	Loss in body weight	Fall in serum albumin concentration	Loss in total serum albumin	Loss in total tissue protein (gm. total urinary N $\times$ 6.25)	$K = \frac{\text{loss total serum albumin}}{\text{loss total tissue protein}}$
	kg	gm per cent	gm		
Z10	1.2	1.82	9.5	199	0.047
Z24	0.9	0.89	4.3	182	0.024
Z14	0.6	0.59	2.7	135	0.020
T56	1.8	0.69	6.5	237	0.027
T67	0.7	0.81	3.4	129	0.026
Averages.	1.04	0.96	5.28	176	0.030

## DISCUSSION

On the basis of the evidence presented (both our own observations as well as those of others) an hypothesis is offered that a relatively constant relationship (about 25 or 30 to 1) exists between dietary induced changes in the total tissue protein and changes in the total circulating serum albumin. In other words, loss (or gain) of tissue protein and of serum albumin caused by diet parallel each other. This conception is based on the existence of a fixed partition between tissue protein and serum albumin, i.e., loss or gain in one is accompanied by a proportional loss or gain in the other. Thus this hypothesis denies the existence of "deposit protein" or of reserves of protein which became available during dietary deficiencies. (When loss of serum albumin occurs in other ways such as hemorrhage, burns, etc., another situation exists which presents other mechanisms.)

It would seem that the existence of such a parallelism between serum albumin and tissue proteins makes it possible to detect the presence and extent of a tissue protein deficiency simply by determining the amount of serum albumin. Since it is also probable that the same parallelism, or biological partition,



exists in the process of replenishment of depleted tissue protein and serum albumin, such information may be of practical value in calculating the amount of protein which must be fed in order to overcome the deficiency

If this idea is correct it is possible, as stated previously, to develop a formula by which the total protein loss may be calculated, if the serum albumin concentration is known. Let the serum albumin tissue protein parallelism be represented by the equation 
$$\frac{\text{Serum albumin depletion in grams}}{\text{Tissue protein depletion in grams}} = K$$
 The serum albumin depletion in grams will be equal to the normal serum albumin concentration (2) of dogs (3.6 gm.) minus the observed serum albumin concentration (S.A.) times the plasma volume (P.V.). When the albumin concentration is given in terms of grams per 100 cc. of serum, the plasma volume should be the number of 100 cc. of plasma present. This figure for the plasma volume is obtained by direct dye determination or estimated by dividing the normal body weight in kilos by 20 and multiplying this figure by 10. Stated again

Serum albumin depletion (grams)

$$= (3.6 - \text{observed albumin concentration S.A.}) \frac{(\text{body weight in kilos} \times 10)}{20}$$

Inasmuch as  $K$  (Table I) is approximately 0.04, one obtains by substituting our first equation

$$\frac{(3.6 - \text{S.A.}) (\text{body weight in kilos}) (10)}{(20) (\text{tissue protein depletion in gm.})} = 0.04 \text{ or simplifying, tissue protein depletion in gm.} = (3.6 - \text{S.A.}) (\text{normal body weight in kilos}) (12.5)$$

The relationship of 1 to 25 (or 30, i.e.  $K = 0.04$  or  $0.03$ ) between serum albumin loss and tissue protein loss was compared with the available data on the relative amounts of each in the intact human body. The amount of serum albumin is easily estimated as 161 gm ( $3500 \times 4.6$ ). Let us assume that nearly all tissue protein is muscle, from Vierordt (7) the weight of the muscles in an average adult is about 28 kilos of which  $1/5$  is protein or 5600 gm. Of course only the parenchyma of the muscle tissue is lost during starvation so that the active protein tissue is less than this. Nevertheless 5600 gm. is but slightly more than 30 times the amount of serum albumin. It seems not unlikely that the relationship for  $K$  may be the same as the relative masses of these two protein compartments of the body.

Certain obvious limitations of the hypothesis here formulated must be emphasized. It applies only when the tissue proteins and serum albumin are altered as a result of diet. It cannot be expected to hold in cases of hypoproteinemia due to blood loss, burns, nephrosis, or liver disease. Another factor is also important, i.e. in depleted patients the measurement of serum albumin concentration may not accurately measure the degree of hypoalbuminemia.

minemia if the normal plasma volume shrinks. For example, if the patient is dehydrated, the resultant hemoconcentration produces a rise in the value of serum albumin and minimizes or even masks completely the existence of the deficiency. This masking effect of dehydration was pointed out clearly by Peters and his coworkers (8) in 1925. It is probable that the persistence of more or less normal plasma albumin concentrations, noted by several observers, in animals placed on certain low protein diets or fasted is the result of such hemoconcentration. Indeed, this phenomenon was noted in experiments on fasting dogs performed in this laboratory (9).

Although the present data are confined to dogs, there is no reason to believe that a similar relationship does not hold true for human beings. There are in the literature but few data of the sort herein discussed. A rough calculation of the data of Bruckman, D'Esopo, and Peters (12) who measured the serum albumin concentration and made concomitant nitrogen balance studies of a malnourished individual during a period of replenishment indicates a value for  $K$  of about 0.02. Nevertheless if we assume that the value for  $K$  for humans is the same as for dogs, and accept as the normal serum albumin concentration the lower limit, 4.6 gm per cent, given by Hawk and Bergheim (10) the equation describing the protein depletion of a malnourished human is: grams protein depletion =  $(4.6 - S.A.)$  (normal body weight in kilos) (12.5).

The practical application of the conception herein presented concerns to a large extent the problem of replenishment of chronic protein deficiencies which are of frequent clinical occurrence. For example, a patient whose body weight in health is 60 kilos and whose serum albumin is 3.6 gm per cent would be deficient by  $(4.6 - 3.6) (60) (12.5) = 756$  gm protein. If such a patient retained but half of the nitrogen consumed, he would require twice 756 gm or 1512 gm. Thus a period of over 2 weeks on a diet providing 100 gm protein per day would be required to reach this amount. To this must be added the requirements for endogenous nitrogen metabolism which would be at least  $4 \times 6.25$  or 26 gm per day. Viewed in this way the therapeutic problem presented by a protein-deficient patient is largely a quantitative one, only by giving a large amount of protein can it be solved. This is particularly difficult when the nitrogen-containing nutriment must be given intravenously or parenterally or when but a short period of time is available for correction. The immense quantities of protein required make the use of human plasma or serum transfusions for this purpose an altogether impractical procedure at least in severely depleted patients. The most promising approach at present is the use of hydrolyzed protein of high biological value (6, 11).

#### SUMMARY

In five dogs placed on a protein-poor diet for 3 weeks, the decline in total circulating plasma albumin was a small (3 per cent) but relatively constant

part of the total nitrogen lost. These data together with observations on dogs by others indicate that there is a constant relationship or partition in the loss (or gain) between plasma albumin and total body protein induced by diet. Based on this relationship a formula is developed for estimating the degree of total tissue protein deficiency from the value of the serum albumin concentration alone. This formula would also apply to the replenishment of protein deficiencies of dietary origin and it indicates that for every gram of increase in serum albumin desired about 30 gm must be retained for increases in other proteins of the body

## BIBLIOGRAPHY

- 1 Peters, J P, Wakeman, M. A., and Eisenman A J, *J Clin Inv*, 1927 3, 491
- 2 Weech A. A. Goettsch E. and Reeves E B, *J Exp Med*, 1935 61, 299
- 3 Elman, R., and Heifetz, C., *J Exp Med*, 1941, 73, 417
- 4 Holman R L., Mahoney, E. B., and Whipple, G H., *J Exp Med* 1934 59, 251
- 5 Madden, S C, Zeldis L. J., Hengerer, A. D. Miller, L L. Rowe, A. P., Turner A P., and Whipple, G H *J Exp Med*, 1941, 73, 727
- 6 Elman, R. Sachar, L A., Horvitz, A., and Wolf H, *Arch. Surg* in press
- 7 Vierordt, H., Anatomische physiologische und physikalische Daten und Tabellen Jena, Gustav Fischer 3rd edition 1906 44
8. Peters J P, Eisenman, A J and Bulger, H. A. *J Clin. Inv* 1925 1, 435
- 9 Elman, R., Horvitz A., and Sachar, L A. unpublished observations.
- 10 Hawk, P., and Berghelm, O., Practical physiological chemistry, Philadelphia, P Blakiston's Son and Co Inc. 11th edition 1937
- 11 Elman, R. *Ann Surg* 1940 112, 594.
12. Bruckman, F S, D'Esopo L M., and Peters, J P, *J Clin Inv*, 1930, 8, 577



# STUDIES ON HYPOALBUMINEMIA PRODUCED BY PROTEIN DEFICIENT DIETS

## II RAPID CORRECTION OF HYPOALBUMINEMIA WITH AN AD LIBITUM MEAT DIET\*

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The practical problem of restoring protein deficiency induced by diet has been studied experimentally by Weech (1) and his coworkers who found a definite regeneration (in the following order of efficacy) when beef serum, egg white, meat, liver, or casein was added to the diet of dogs. For example, after a 3 week depletion period, these workers observed an almost complete return to normal when 5 gm per kilo per day of beef chuck was added to the diet for 10 days. This was about twice the rate of regeneration in other experiments in which half this amount of meat was given.

In surgical and other patients suffering from hypoproteinemia of dietary origin restoration of serum protein must often be achieved in a relatively short period of time. It has seemed important, therefore, to determine how fast the serum protein can be restored to normal when much larger amounts of protein are given. This was the purpose of the present experiment.

### Methods

Five dogs were fasted for 3 weeks however, they were allowed water *ad libitum* and some of them were given Ringer's solution by gavage. At the end of 3 weeks they were started on the regeneration diet, which consisted solely of raw lean horse meat given *ad libitum* i.e., sufficient meat was offered so that some of it was left at the end of each 24 hour period. This was then subtracted from the total to record the amount actually eaten.

*Technical Methods*—Hematocrits were determined on heparinized blood. Plasma proteins were then determined and fractionated by methods already described (2). The blood volume was determined by using the Evan's blue dye T 1284 according to a simplified technique as follows.

The method for the determination of plasma volume in dogs was adapted from that described by Gibson and Evelyn (3). The main difference was the use of the Klett

\* Aided by a grant from Mead Johnson and Co. Evansville, Indiana.

photoelectric colorimeter instead of the Evelyn apparatus employed by these workers. Many of these details were worked out in the Department of Physiology of the Washington University Medical School, and the authors are indebted to Miss Rolf for her help in applying them to our purposes.

An initial heparinized blood sample was first obtained. Through the same needle a 200 mg per cent saline suspension of Evans blue was injected, the total dose being 1 mg of dye per kilo of body weight. To insure the accurate introduction of the calculated amount of dye a 3 way-stop-cock and an 18 inch rubber tubing of small diameter connected with a syringe barrel was employed. After the initial blood sample was drawn saline was allowed to flow by gravity from the syringe barrel into the dog's vein to test the position of the needle in the vein. This assured, the dye solution was added by pipette under the surface of the saline solution. Toward the end of the injection small portions of saline were added to wash the last remnants of dye from the tubing into the vein. The initial time of mixing (zero point) was considered to be the time of the first saline washings.

Samples of heparinized blood for dye estimation were taken subsequently at recorded intervals of approximately 15, 25, and 35 minutes from the initial (zero) time. All blood samples were centrifuged for 30 minutes at 3000 R.P.M. 1 cc of plasma from each of the 4 samples was measured into test tubes and 5 cc. of saline added. After the contents of the tubes were mixed, readings were immediately made on the Klett photoelectric colorimeter using 620 and 540 filters, the two filters are used to correct for any hemolysis present in the dye samples. The blank dye-free plasma was set at zero. The correct  $R$  for each sample was calculated according to the formula which is nearly the same as that used by Gibson and Evelyn (3)

$$R = \frac{(R_{620}) \times 20 - (R_{540})}{19.5}$$

The corrected  $R$  values for each of the 3 samples were then plotted against time and a line was drawn through these points and carried back to zero.

The concentration of dye (as mg per cc.) for the  $R$  at zero time was read off a previously prepared graph which established the relationship between  $R$  and the concentration of dye. This graph was made by setting up several series of tubes each containing a known amount of dye and 1 cc of plasma, made up to 6 cc with saline. Because we found such dilute solutions of Evans blue to be unstable, a fresh 1 mg per cent saline solution was made from the 200 mg per cent dye solution each time a series was to be read. A straight line always resulted at least in the range of dye concentration used in our experiments.

The plasma volume in cubic centimeters was then calculated by dividing the milligrams of dye injected by the milligrams of dye present in 1 cc of plasma at zero time.

#### FINDINGS AND COMMENTS

The main results of the experiment are recorded in Table I, which shows that after a 3 weeks fast the *ad libitum* meat diet resulted in a complete regeneration in 1 week of both the concentration of serum albumin and the total amount

thereof. Indeed the total circulating albumin increased well above normal, although this was undoubtedly a reflection of the increased plasma volume which accompanied the fall in red cell volume (hematocrit). There was very little further increase in the albumin during the 2nd week of the regeneration period. The fall in body weight and its subsequent rise, though a little more pronounced, roughly paralleled the behavior of the serum albumin. The red cell volume decreased but slightly during the fast, during the regeneration period it fell markedly, a reflection of the tremendous increase in the plasma

TABLE I

*Changes during a 3 Week Fast and during 2 Weeks of an ad Libitum Meat Diet*

Dog	Initial					After 3 wks.					After 4 wks.					After 5 wks.				
	Wt.	Hem.	Alb.	Glob.		Wt.	Hem.	Alb.	T. A.	Glob.	Wt.	Hem.	Alb.	T. A.	Glob.	Wt.	Hem.	Alb.	T. A.	Glob.
	kg	per cent	gm. per cent	gm. per cent		kg	per cent	gm. per cent	gm	gm. per cent	kg	per cent	gm. per cent	gm	gm. per cent	kg	per cent	gm. per cent	gm	gm. per cent
E6	5.6	48.8	2.65	2.75		4.3	44.0	2.23	7.52	3.01	5.0	40.9	2.36	9.78	3.11	5.3	33.3	2.44	9.83	3.40
E2	7.4	46.7	3.64	2.78		5.4	50.4	3.07	8.96	2.56	7.1	39.6	3.54	13.72	2.44	7.4	32.5	3.42	17.41	2.70
F3	8.4	45.1	3.30	2.90		6.8	42.4	2.94	14.38	3.58	8.7	36.2	3.22	17.90	2.61	8.7	38.0	3.30	19.31	3.57
S9	8.0	51.1	3.26	2.17		6.4	43.2	2.76	8.75	2.52	6.7	35.1	3.21	15.20	2.96	7.4	35.6	3.50	16.66	3.46
S2	13.4	53.3	3.14	3.52		10.3	46.2	2.46	15.01	4.12	12.4	41.1	2.99	26.40	3.56	12.8	44.0	3.20	25.76	3.82
Averages																				
Wt.	8.6					6.8					8.0					8.3				
Hem.		49.0					45.2					38.6					36.7			
Alb.			3.22					2.69					3.10					3.17		
T. A.				13.9*					10.92					17.00					17.79	
Glob.				2.82						2.96					3.00					3.39

\* Estimated.

Abbreviations wt, body weight hem. hematocrit alb. plasma albumin glob., plasma globulin T. A. total plasma albumin.

volume. The serum globulin, unchanged during the fast and for the 1st week of the regeneration period showed a pronounced increase in the 2nd week.

The amount of meat ingested by the animals was surprisingly large and averaged 250 gm per kilo per day, *i.e.*, the dogs consumed one-fourth of their body weight each day. Inasmuch as meat is composed of one-fifth protein the actual protein intake was 50 gm per kilo of body weight per day. It was interesting to note that this large amount was eaten even during the last days of the experiment, *i.e.* when body weight and serum protein had returned to normal.

These findings indicate first, the tremendous amount of protein which a depleted dog will ingest, and second, the rapidity with which such a high protein intake will lead to a complete correction of hypoproteinemia induced by a

3 weeks fast. The practical inference is obvious and points the way toward rapid relief of clinical hypoproteinemia by the administration of sufficient protein. This is suggested in the accompanying study from this laboratory (2) in which a partition of about 30 to 1 was found in the distribution of dietary nitrogen loss or gain between tissue and serum proteins respectively, in other words evidence was presented showing that the body tissues will take up 30 gm of nitrogen for every gram which goes to the regeneration of serum protein. This explains why large amounts of protein are needed to correct hypoproteinemia. The present findings are corroborative in that they indicate that if the protein intake is unusually large (in this case 50 gm per kilo per day) regeneration of serum proteins will be complete within a week. We have no data as to whether this return to normal might not have occurred within a few days. However, a continuation of the high protein intake, *1 c* during the 2nd week did not raise the albumin level any further though for some reason it did instigate an increase of the globulin fraction during this last period.

The failure of the red cells to regenerate as shown by the fall in the hematocrit is not surprising in view of the well known fact that restoration of red cells requires a number of weeks. From the practical point of view this is not a serious deficiency inasmuch as the important clinical manifestations of protein depletion are concerned with the plasma and not with the erythrocyte portion of the blood. The increase in the plasma volume during the regeneration period (from an average of 748 to 897 cc during the 4th week) was probably the reason for the particularly pronounced fall in the red cell volume during this time.

#### SUMMARY

Serum albumin depletion, induced by a 3 weeks fast, was completely corrected within 1 week by the ingestion of a diet consisting solely of meat administered *ad libitum*. The average protein intake was 50 gm per kilo of body weight per day. A 2nd week of the same diet produced no further increase in serum albumin though it did lead to an increase in the globulin fraction.

#### BIBLIOGRAPHY

- 1 Weech, A. A , *Harvey Lectures*, 1938-39, 34, 59
- 2 Sachar, L. A , Horvitz, A , and Elman, R , *J Exp Med* , 1942, 75, 453
- 3 Gibson, J. G , II, and Evelyn, K. A , *J Clin Inv* , 1938, 17, 153







# THE LOCALIZED ACTION ON THE SPINAL CORD OF INTRAMUSCULARLY INJECTED TETANUS TOXIN

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The pathogenesis of local tetanus has been the subject of much dispute. Until recently, the most generally accepted view was that of Marie and Morax (1902) and Meyer and Ransom (1902-03). They believed that local tetanus is the result of the action of tetanus toxin on the anterior horn cells of the spinal cord, the toxin reaching the central nervous system by way of the axons of the motor nerves. On the other hand, Vaillard and Vincent (1891) and Zupnik (1905) held that local tetanus is the result of the action of the toxin directly on the muscle, and that the toxin reaches the central nervous system through the blood stream rather than along peripheral axons, causing there generalized rather than local tetanus.

No one doubts the susceptibility of the central nervous system to tetanus toxin. If toxin is injected directly into the spinal cord in small amounts, a typical local tetanus may result (Fröhlich and Meyer, 1915). The question then remains whether local tetanus following intramuscular injection of small amounts of toxin is due to the action of the toxin on the segments of the spinal cord which innervate the site of injection, or on some peripheral structure. If the former is true, it remains to be demonstrated how the toxin reaches the spinal cord.

In addition to the immunologic evidence for the nerve transport of tetanus toxin recently reviewed by Friedemann, Hollander and Tarlov (1941), certain other experiments have supported this theory. Courmont and Doyon (1894) injected tetanus toxin into the right hind paw of a dog. When the animal had developed stiffness limited to the right hind leg, they cut the spinal cord at the union of the lumbar and thoracic levels and sectioned all the dorsal roots. Stimulation of the dorsal roots with an inductorium was now effective in producing a reflex contraction with a current strength on the tetanic side one-fourth that necessary on the normal side. After removal of the spinal cord, stimulation of the ventral roots was effective at the same strength of stimulus on both sides. They therefore concluded that the action of the toxin is not on the peripheral motor elements of the reflex arc and must be either on the sensory nerves or on the spinal cord.

An experiment reported by Sherrington (1905) further clarifies the situation

potential of A fibers following a single stimulus was equal on the right and left. By increasing the amplification proportionally on the two sides, comparable records could be obtained at higher amplification.

## RESULTS

(a) *The Muscular Response*—The animal with well developed local tetanus exhibits a striking picture suggestive of reflex hyperactivity. A weak stimulus to the affected limb produces a vigorous increase in the extension of the limb. This type of response might depend upon any or all of a variety of factors. For example, long lasting repetitive responses of the nerves, myoneural junctions, or muscles, to single stimuli, could account for it, independent of any change in the spinal mechanisms. The experiments of this and the succeeding section were designed to test this possibility.

The augmented response of the tetanic leg to a weak stimulus, described above, was studied in a series of cats by recording the electric and mechanical responses of the calf muscles. The stimulus used was either a sudden tap on the Achilles tendon or a shock to the sciatic nerve. The difference between the tetanic and the control legs was apparent, as can be seen in Fig. 1, where A and B represent the tetanic side and D and E represent the control. The increased mechanical response of the tetanic leg is accompanied by a fusillade of muscle action potentials.

If this augmented response depended upon an altered response of the motor nerve or of the muscle, the difference between the sides should persist after section of the sciatic nerve central to the stimulating electrodes. As may be seen in Fig. 1, C and F, when this was done the electromyograms of the two sides were indistinguishable and the mechanograms differed only in amplitude.

The augmented response of the leg with local tetanus does not depend, therefore, upon a change at the myoneural junction, in the muscle, or in the motor nerve. This is in agreement with the experiments of Courmont and Doyon (1894) and others. Repetitive responses of the muscle to single stimuli applied to the cut motor nerve, as described by Harvey (1939), were not observed by us. Differences in technique may account for the differences in result. Although our experiments do not exclude changes in the muscle due to tetanus toxin, muscular changes do not explain the phenomena described.

(b) *The Peripheral Nerve*—The following experiments demonstrate that the augmented response after a single excitation of the sciatic nerve, described above, is not due to repetitive activity of either the motor or the sensory components of the nerve trunk.

After section of the posterior tibial and peroneal nerves in the popliteal space, recording electrodes were placed on the branch of the posterior tibial nerve which innervates the lateral head of the gastrocnemius muscle, the portion of the nerve under the distal electrodes was crushed in order to secure

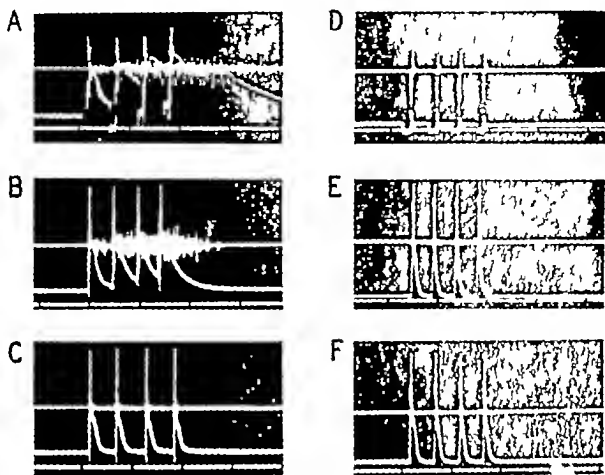


FIG. 1. The augmented response of the tetanic leg and its dependence on the type of stimulus are. Mechanical and electric records from the calf muscles of a cat with unilateral locomotor tetanus 4 days after injection of 1.131 cat u.L.D. of toxin. The spinal cord had been sectioned at the level of the 12th thoracic vertebra 5 hours before the records were taken. In each record the uppermost line is the electrogram taken from needle electrodes in the belly of the muscles; the other at the ankle. The second line is the myogram obtained with an optical frictionless torsion-spring myograph. The peak of each contraction curve obscures part of the corresponding, initial electrogram. The bottom line is a time scale marking intervals of 1 second.

A. Responses on the tetanic side to taps on the Achilles tendon.

B. Responses on the tetanic side to brief condenser discharges applied to the intact sciatic nerve at the hip.

C. Responses on the tetanic side as in B after section of the sciatic nerve central to the stimulating electrodes.

D, E, and F. The same as A, B, and C respectively on the unaffected side.

monophasic records. Stimulating electrodes were placed on the sciatic nerve at the hip. The nerve was cut central to the stimulating electrodes and excited with maximal brief condenser discharges.

Of 14 animals studied, 10 showed no repetitive response. Repetitive re-

sponses of equal degree were present on both sides in one instance, in two others there was a repetitive response limited to the side with local tetanus, and in one, there was a repetitive response on each side, but predominantly on the side with local tetanus

The excitability of the branch of the posterior tibial nerve to the lateral head of the gastrocnemius muscle was studied *in situ* in 8 animals with the preparation described above. Strength-duration curves were determined by the method of Hill (1936). There was no significant variation in either the rheobase or the time constant between the nerve of the tetanic and that of the unaffected leg.

The amplitudes of the maximal action potential of the A fibers of the nerve to the gastrocnemius muscle of the tetanic and control sides were compared in 22 animals. In 12, the spike amplitude of the tetanic side exceeded that of the control, in 6 there was less than 10 per cent difference between the two sides, and in 4, the spike of the control exceeded that of the tetanic side. Differences in the degree of shunt around the nerve and recording electrodes may account in part for the difference in the spike amplitude observed.

Thus occasionally there may be changes in the peripheral nerve in local tetanus. Yet the typical responses of local tetanus were present in many experiments in which repetitive response to single stimuli did not occur in the peripheral nerves. In every instance in which repetition was demonstrated in the peripheral nerve by the technique outlined above, the presence of the abnormal response was obvious before the special tests were made. In order to avoid confusion of peripheral and central effects, the experiments of the succeeding sections relate to animals in which there was electrographic evidence that the sciatic nerve, when severed from the central nervous system, did not respond repetitively to single stimuli.

(c) *Changes in the Spinal Cord*—Since the augmented activity of the calf muscles associated with local tetanus is, as demonstrated above, independent of changes in the muscle, neuromuscular junction, and peripheral nerve, its origin must by exclusion be either in the dorsal root ganglia or in the spinal cord. The following experiments were devised to study these possibilities.

The spinal cord of 18 cats with local tetanus limited to one hind leg was sectioned either at the first, or more frequently the 12th thoracic level. Stimulating electrodes were placed on the sciatic nerves at the hip, and the peroneal and posterior tibial nerves, the nerves to the biceps femoris and hamstring muscles, and in some instances the femoral nerves were sectioned. Recording electrodes were placed on the central end of the divided branch of the posterior tibial nerve which innervates the lateral head of the gastrocnemius muscle, the portion of the nerve under the distal electrode was crushed in order to secure monophasic records.

The electrograms obtained from this preparation on stimulating the ipsi-

lateral sciatic nerve differ strikingly on the tetanic as compared to the control side. A single strong condenser discharge is followed by 3 negative waves. The 1st of these is similar on the two sides and represents the volley of impulses initiated by the stimulus at the hip and descending the nerve. The 2nd wave begins 3.5 to 4 milliseconds after the stimulus. Since it is abolished by section of the sciatic nerve central to the stimulating electrodes it may be called the early reflex response. This wave is small in comparison to the amplitude of the 1st wave resulting from maximal activity of the A fibers of the nerve. If the strength of stimulus is increased from subthreshold to supramaximal values by steps, the early reflex response undergoes a series of changes: it increases in amplitude until it reaches a maximum at a strength of stimulus still submaximal as judged by the amplitude of the 1st wave and then decreases with stronger stimuli. The early reflex response resembles the *s* wave described by Renshaw (1940) in the reflex responses from ventral roots.

If the sciatic nerve is stimulated repetitively at a frequency of 4 to 8 per second, the early reflex response undergoes a decrease in amplitude which may be interpreted as either fatigue or inhibition. This decrease is regularly less pronounced on the side which is subject to local tetanus than on the control side. Fig. 2 illustrates this difference. In other respects the early reflex response is similar on the two sides.

About 7 to 11 milliseconds after the stimulus a 3rd wave occurs. Like the 2nd wave, this disappears on section of the sciatic nerve central to the stimulating electrodes and hence may be called the late reflex response. It is irregular in form on both the tetanic and the control sides but more strikingly so on the tetanic. It probably represents the fusion of the responses of several groups of neurons firing asynchronously over a period of 6 to 16 milliseconds. This wave starts earlier, lasts longer and is usually of greater amplitude on the tetanic than on the normal side, as may be seen in Fig. 3. Exceptionally the amplitude of the late reflex response of the tetanic side is no greater than that of the control.

If the sciatic nerve is stimulated at the rate of 4 to 8 shocks per second the amplitude of the late reflex response on the control side either diminishes or remains unchanged. The same procedure on the tetanic side usually leads to an increase in the amplitude of the late reflex response. The latency of this response usually shortens with repetitive stimulation almost invariably more on the tetanic than on the control side (Fig. 3).

If the response is examined with high amplification and with the coupling condensers of the amplifiers arranged most favorably to record activity of high frequency considerably more after-discharge is seen to follow the 3 waves described on the tetanic side than on the control. Exceptionally the two sides showed no difference in this respect. Repetitive stimulation at 4 to 8 shocks per second invariably results in an increase of the amplitude

and often of the duration of the after-discharge on the tetanic side, which may last as long as 3 seconds after the final stimulus. This is in sharp con-

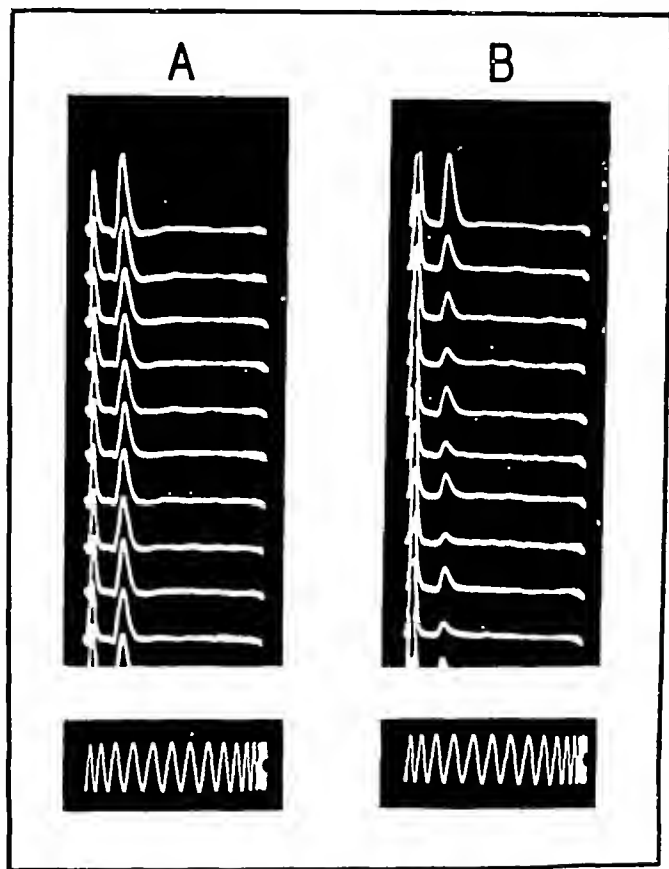


FIG. 2 Greater decrease of the early reflex response to repetitive stimulation on the control side. Electrograms from the nerve supplying the lateral head of the gastrocnemius muscle, 3 days after injection of 1/100 cat MLD of tetanus toxin into the right calf, in a cat in which the development of symptoms of local tetanus was prevented by extensive denervation of the legs 19 hours after the injection.

A Response of the nerves of the tetanic side to 8 stimuli per second to the sciatic nerve at an intensity which produces a maximal amplitude of the 2nd wave.

B The same as A on the unaffected side.

trast to the electrogram of the control leg, in which summation is uncommon and never as great as may be seen in the injected leg. Fig. 4 illustrates the after-discharge on the two sides of an animal with local tetanus.

Tetanus toxin injected into the calf muscles therefore produces a clearly



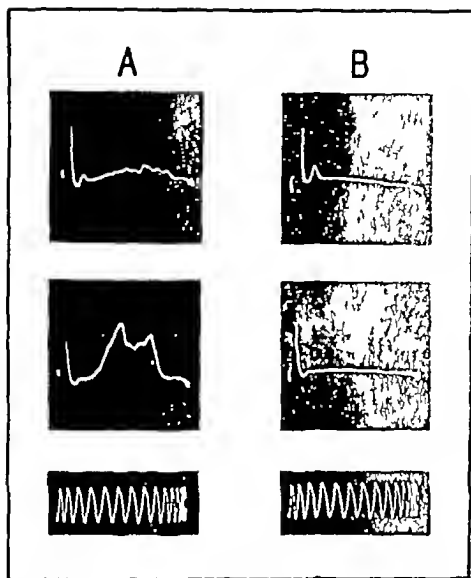


FIG. 3. Differences in the late reflex response of tetanic and control leg. —Electrograms from the nerve supplying the lateral head of the gastrocnemius muscle 4 days after injection of 1/100 cat M.L.D. of tetanus toxin into the right calf in a cat in which the development of symptoms of local tetanus was prevented by extensive denervation of the legs 18 hours after the injection.

A. Upper picture—response on the tetanic side to a single strong stimulus to the sciatic nerve. The 3 waves described in the text are shown from left to right. Middle picture—response to the last of 8 stimuli delivered within 1 second showing summation and change of latency of the late reflex response and decline of the early reflex response. Lower picture—time signal; each cycle represents 2 milliseconds.

B. The same as A on the unaffected side. There is no summation in the late reflex response and the decline of the early reflex response is more marked than on the tetanic side.

recognizable alteration in the pattern of nerve impulses which are discharged by the spinal cord in response to a stimulus applied to the sciatic nerve.

(d) *Effect of Section of Dorsal Roots on Electrogram of Nerve*—Three further

possible mechanisms might explain the augmented response of the tetanic leg. It might be due to an altered state of the spinal cord itself, or of the dorsal root ganglion, or to a change in the activity of peripheral sensory mechanisms. The latter two possibilities were tested in the following experi-

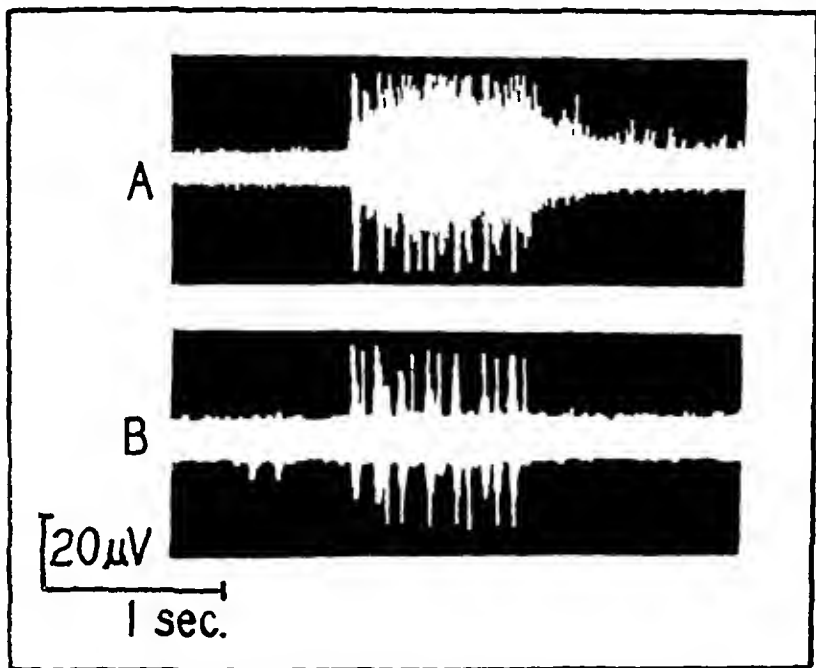


FIG. 4 Augmented after-discharge on the tetanic side. Electrograms from the nerve which innervates the lateral head of the gastrocnemius muscle, following stimulation of the 7th lumbar dorsal root, in a cat with unilateral local tetanus 9 days after injection of  $1/75$  M.L.D. of tetanus toxin. The spinal cord had been sectioned at the level of the 12th thoracic vertebra 5 hours before the records were taken, and all the dorsal roots below this level cut bilaterally. These records were taken at high amplification, with the coupling condensers arranged to emphasize asynchronous discharge of the nerve.

A. Electrogram of the affected side upon repetitive stimulation of the sciatic nerve.

B. The same as A on the unaffected side.

ments by complete deafferentation of the spinal cord by section of the dorsal roots central to the dorsal root ganglia.

The effect of section of the dorsal roots was studied in 11 cats with tetanus limited to one leg. The spinal cord was sectioned under ether anesthesia at the level of the 12th thoracic vertebra, and the lamina of the lumbar vertebrae

removed. The animal was then allowed to recover from the effects of the anesthesia, and was symmetrically fixed as in earlier experiments. Stimulating electrodes were then placed bilaterally upon the sciatic nerve and recording electrodes on the nerve to the lateral head of the gastrocnemius muscle. In each case the presence of tetanus limited to one leg was confirmed by record

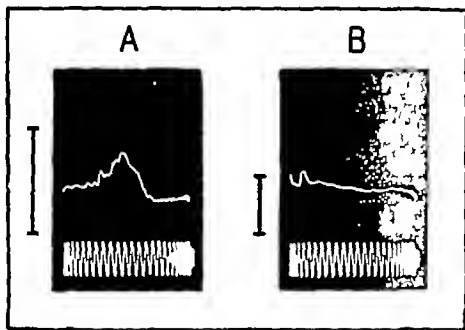


FIG 5 Reflex response to dorsal root stimulation. Electrograms from the nerve which innervates the lateral head of the gastrocnemius muscle following stimulation of the 6th lumbar dorsal root in a cat with unilateral local tetanus 7 days after injection of 1/75 cat MLD of toxin. Five hours before the records were taken the spinal cord was cut at the level of the 12th thoracic vertebra. All the dorsal roots below this level were sectioned bilaterally. The vertical lines at the left of the pictures represent the relative heights of the maximal spikes of the A fibers of the respective nerves; the amplitude of the response of the unaffected side must therefore be doubled to compare it with that of the tetanic side.

A. Upper line: electrogram from the nerve of the injected leg after a single strong stimulus to the dorsal root. Lower line: time signal; each cycle represents 2 milliseconds.

B. The same as A on the unaffected side. In this experiment the early reflex response was greater on the control than on the tetanic side. The late reflex response showed the usual predominance on the tetanic side.

ing the electric response of the nerve supplying the gastrocnemius on stimulation of the sciatic nerve. Four or 5 hours after the section of the spinal cord the dura mater was laid open and the dorsal roots of the lumbosacral segments cut central to the dorsal root ganglia. The cauda equina was sectioned at the upper border of the sacrum. The dorsal roots were then stimulated through silver wire shielded electrodes; stimulation at the 7th lumbar level was usually most effective.

In 7 of 11 experiments, the condition of the spinal cord after this procedure seemed satisfactory as judged by the responses elicited by stimulating the dorsal roots. In 2 of these 7, the responses of the left and right sides were equal. In the remaining 5, the electrogram of the tetanic side showed the changes typical of local tetanus as outlined in Section (c). A single strong condenser shock evoked 2 negative waves, corresponding to the 2nd and 3rd waves, the reflex responses, seen following stimulation of the sciatic nerve. In all 5 experiments, repetitive stimulation of the dorsal root of the tetanic side at the rate of 4 to 8 shocks per second resulted in little or no decline of the early reflex response, and an increase in the amplitude of the late reflex response. When the corresponding dorsal root of the control side was stimulated, the initial magnitude of the response was smaller (Fig. 5), and after repeated stimulation there was either no change or a decrease in the magnitude of the late response. In 4 of these 5 animals, repetitive stimulation of the dorsal root elicited an after-discharge lasting about 0.4 second on the injected side when examined with high amplification as in earlier experiments (Fig. 4). An after-discharge was never seen in the nerves of the control side under similar conditions.

The origin of the augmented activity of the tetanic gastrocnemius muscle after stimulation of the sciatic nerve is therefore within the spinal cord, and limited to the same side as the local tetanus.

(e) *Effect of Denervation after Injection of Toxin on the Development of Local Tetanus in the Spinal Cord*—It is conceivable that the changes in the spinal cord described above are dependent on changes in the peripheral structures. For example, changes in the muscle following intramuscular injection of tetanus toxin might result in a prolonged continuous bombardment of the spinal cord by afferent impulses which might produce the observed changes. This possibility can be excluded by sectioning the nerves of the injected area before the appearance of local tetanus.

After the injection of 1/100 cat MLD of tetanus toxin into the gastrocnemius muscle neither the physical signs nor changes in the electrogram of nerve characteristic of local tetanus are present within the first 24 hours. The right calf muscles of 3 animals were injected with 1/100 cat MLD of tetanus toxin. Eighteen to 20 hours later, at a time when none of these animals showed physical signs of tetanus, the following operations were performed bilaterally under ether anesthesia. The femoral and obturator nerves were cut in the groin, and the nerve to the hamstring muscles at the hip. The popliteal space was cleared of fat, and all the branches of the peroneopopliteal nerve were cut—namely, the nerve to the biceps femoris muscle, and the peroneal, posterior tibial, and sural nerves. For later identification, a black silk suture was tied to the central end of the cut branch of the posterior tibial nerve which innervates the lateral head of the gastrocnemius muscle. Three, 4, and 5 days

after injection, when control cats injected at the same time with the same amount of toxin exhibited typical local tetanus, there were no signs of tetanus in the animals upon which operations had been performed. The hips, knees, and ankles of the latter were flaccid, and both upper legs were held abducted. Under ether anesthesia the spinal cord was cut at the level of the 12th thoracic vertebra, after which the animals were permitted to recover from the effects of the anesthesia. On each side, stimulating electrodes were placed on the sciatic nerve and recording electrodes on the branch of the posterior tibial supplying the lateral head of the *gastrocnemius*. The pattern of the electrogram of the nerve to the *gastrocnemius* muscle of the injected leg agrees in all respects with that previously described for the nerve when the muscular picture of local tetanus is present. The electrogram of the control side is likewise the same as that of the uninjected leg in animals in which the innervation is intact. Figs 2 and 3, which have been used to illustrate the characteristic waves, are from animals in which the leg had been denervated.

In local tetanus, therefore, changes develop in the spinal cord even though section of the peripheral nerves 18 to 20 hours after injection of the toxin has prevented the appearance of the peripheral signs of local tetanus.

(f) *Effect of Denervation before Injection of Toxin on the Development of Local Tetanus in the Spinal Cord*—The localization of the spinal effects of intramuscularly injected toxin to the region supplying the innervation of the injected area is difficult to explain unless the toxin reaches the cord by way of the nerve trunks. In this case section of the nerve trunks supplying the area of injection before the injection of the toxin should prevent the spinal effects. The following experiments were devised to test this.

The procedure was the same as that described in the preceding section except that the section of nerve trunks was performed shortly before the injection of the toxin. Three animals so prepared received 1/100 cat M.L.D. of tetanus toxin into the right calf muscles. Three, 4, and 5 days later none of the animals showed signs of local tetanus. The spinal cord was cut under ether anesthesia and the electrograms from the nerves supplying the lateral head of the *gastrocnemius* were studied as in the previous sections. None of the changes characteristic of local tetanus was present on either side in these animals.

The localized action of tetanus toxin on the spinal cord when the toxin is injected into the calf muscles can therefore be prevented by cutting the nervous pathways which connect the area of injection with the cord.

(g) *Effect of Local Trauma on the Localization of Tetanus*—It has been suggested that the tetanus toxin reaches the central nervous system through the circulation, but that the trauma of injection determines its localization to that part of the spinal cord from which the innervation of the site of injection arises. In 5 cats, 0.4 cc. of tetanus toxin which had been inactivated by boiling was

injected into the left calf muscles at the same time that active toxin was injected into the muscles of the right calf. In no instance did signs of local tetanus appear in the left leg, nor did oscillographic records from the nerves of the left leg 2 to 4 days after injection reveal the changes characteristic of local tetanus. The trauma of injection, therefore, played no rôle in the localization of the tetanus. Gumprecht (1895) excluded this possibility in a more drastic fashion. He injected tetanus toxin into the right hind leg and croton oil into the left foreleg of mice. Local tetanus appeared in the former but not the latter leg.

#### DISCUSSION

The experiments reported in Sections (a) to (d) demonstrate that local tetanus in the cat resulting from the intramuscular injection of toxin is associated with a characteristic response originating in that region of the spinal cord from which the innervation of the injected area arises. The experiments of Section (e), in which the nerves of the legs were sectioned after the injection of toxin but before the appearance of any signs of tetanus demonstrate further that the change in the spinal cord is not dependent upon changes in the muscle or neuromuscular junction but represents an action of the tetanus toxin on the spinal cord itself.

How, then, does the toxin injected into the leg reach the corresponding segment of the cord? If it were carried from the site of injection to the spinal cord only through the blood stream, it is difficult to understand why its action is limited to this small segment. With the doses of toxin used the contralateral portion of the spinal cord at the same level remains unaffected. The localization of tetanus is more understandable if the toxin be supposed to ascend the peripheral nerves to the spinal cord. This view is supported by the experiments of Section (f), in which the action of the intramuscularly injected toxin on the spinal cord was prevented by section of the nerves of the leg before the injection of the toxin. This theory of the path of transport, as well as the logical steps leading up to it, were probably first proposed by Gumprecht (1894, 1895). The present observations establish facts which are adequately explained by this theory and by none other yet advanced. It may be concluded that in local tetanus the toxin is carried to the spinal cord by way of peripheral nerves.

The experiments reported give no hint as to which element of the peripheral nerve may be the pathway of the toxin to the central nervous system. Gumprecht believed that the tissue spaces of Key and Retzius were the route. Marie and Morax (1902) and Meyer and Ransom (1902) suggested that the ascent was through the axis cylinder itself.

Abel (1934, 1935, 1938) argued that the peripheral nerves cannot serve as pathways for diffusible substances to the central nervous system. He questioned the technique of investigators who had reported the passage of dyes

up nerves to the spinal canal Perdrau (1937), however, used techniques free from the objections raised by Abel, and confirmed the previous results. He demonstrated that the central end of the cut sciatic nerve of anesthetized cats is capable of absorbing dyes from solutions into which the nerves are dipped, and that these dyes diffuse up the axis cylinder as far as the spinal cord at a rate sometimes as fast as a centimeter per hour. Perdrau pointed out that the passage of substances through the axis cylinder is compatible with de Renyi's observation that the consistency of the axis cylinder is that of a soft jelly.

The suggestion that tetanus toxin reaches the central nervous system by way of the peripheral nerves is not unique. Strong evidence indicates that the viruses of the poliomyelitis (Bodian and Howe, 1941) and of rabies (di Veste and Zagari, 1889), for example, reach the central nervous system in this way.

#### SUMMARY

Local tetanus limited to one leg was studied in cats after intramuscular injection of tetanus toxin.

1. The electric and mechanical response of the affected muscle after a single stimulus to the intact sensory motor nerve is greater in amplitude and duration than the response of the corresponding muscle of the unaffected leg (Fig. 1).

2. This augmented response of the muscle is associated with an augmented response arising from the ipsilateral portion of the spinal cord, while the contralateral part of the cord is unaffected, as demonstrated by electrographic records from the motor nerves (Figs. 2 to 5).

3. The augmented muscular response is abolished when the reflex arc is broken, but the augmented response in the spinal cord is independent of changes in the muscle, the neuromuscular junction, the afferent and efferent peripheral nerves, and the dorsal root ganglia.

4. The augmented spinal response develops in the absence of the peripheral signs of local tetanus. Hence the pathogenesis of the altered state in the spinal cord is independent of the peripheral effects of the toxin.

5. In local tetanus, therefore, the toxin injected intramuscularly acts selectively upon the segments of the spinal cord which supply the innervation of the injected area.

6. The augmented spinal response may be prevented by section of the nerve trunks supplying the area of injection prior to the injection of the toxin.

7. It is concluded that in local tetanus the toxin is carried to the spinal cord by way of peripheral nerves.

#### BIBLIOGRAPHY

Abel, J. J., *Science*, 1934, 79, 122.

Abel, J. J., Evans, E. A., Jr., Hampil, B., and Lee, F. C., *Bull. Johns Hopkins Hosp.*, 1935, 56, 84.

- Abel, J J , Firor, W M , and Chalian, W , *Bull Johns Hopkins Hosp* , 1938, **63**, 373
- Abel, J J , Hampil, B , and Jonas, A F , Jr , *Bull Johns Hopkins Hosp* , 1935, **56**, 317
- Bodian, D , and Howe, H. A. , *Bull Johns Hopkins Hosp* , 1941, **68**, 248
- Courmont, J , and Doyon, M , *Arch physiol norm et path* , 1894, **16**, series 5, 391
- di Vestea, A. , and Zagari, G , *Ann Inst Pasteur* , 1889, **3**, 237
- Fildes, P , in Fildes, P , and Ledingham, J C G , *A system of bacteriology in relation to medicine*, London, His Majesty's Stationery Office, 1929, **3**, 298
- Friedemann, U , Hollander, A. , and Tarlov, I M , *J Immunol* , 1941, **40**, 325
- Fröhlich, A , and Meyer, H H , *Arch exp Path u Pharmacol* , 1915, **79**, 55
- Green, C C , *Ann Surg* , 1937, **105**, 998
- Gumprecht, F , *Deutsch med Woch* , 1894, **20**, 546
- Gumprecht, F , *Arch ges Physiol* , 1895, **69**, 105
- Harvey, A. M , *J Physiol* , 1939, **98**, 348
- Hill, A V , *Proc Roy Soc London, Series B*, 1936, **119**, 440
- Marie, A , and Morax, V , *Ann Inst Pasteur* , 1902, **16**, 818
- Meyer, H H. , and Ransom, F , *Arch exp Path u Pharmacol* , 1902-03, **49**, 369
- Perdrau, J R , *Brain*, 1937, **60**, 204
- Ranson, S W , *Arch Neurol and Psychiat* , Chicago, 1928, **20**, 663
- Reimann, H A. , *Arch Int Med* , 1941, **68**, 325
- Renshaw, B , *J Neurophysiol* , 1940, **3**, 373
- Sherrington, C S , *Proc Roy Soc London, Series B*, 1905, **76**, 269
- Vaillard, L , and Vincent, H , *Ann Inst Pasteur* , 1891, **5**, 1
- Zupnik, L , *Deutsch med Woch* , 1905, **31**, 1999



# COPPER AND COBALT RELATED HEMOGLOBIN PRODUCTION IN EXPERIMENTAL ANEMIA\*

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Copper has been shown to have a definite effect in anemias due to a milk diet (11) and we have indicated a probable effect in experimental anemia due to blood loss (12, 4). The experiments below show the effect of various doses of copper alone and combined with the standard dose of iron. The hemoglobin production is somewhat irregular, suggesting that larger doses of copper may at times inhibit hemoglobin production.

Cobalt has been used by various investigators especially during the past ten years. Some claim that cobalt stimulates hemoglobin production (10) or that polycythemia can be produced in various animals by cobalt feeding (14, 3). Others find no definite evidence that cobalt influences hemoglobin production (1). Many of these conclusions are reviewed in a recent paper by Frost, Spitzer, Elvehjem, and Hart (6).

Among other difficulties, a definition of *polycythemia* in dogs is not satisfactory. The polycythemia values given in many papers for dogs come within the range which we consider normal. The dogs used in this laboratory for years to test hemoglobin production in anemia due to blood loss are bred and raised in our kennels. Not of a pure strain, they are pretty uniform as to type—the white bull terrier strain predominating. These adult dogs when considered to be perfectly normal on a mixed diet present a 50 to 55 per cent hematocrit, 19 to 20 gm. hemoglobin per 100 cc. and 7 to 9 million red cells. If one takes a dog with 15 gm. hemoglobin and raises the level to 20 gm. hemoglobin it does not convince us that this is a true polycythemia for the dog. Perhaps diet, environment and inheritance all come into the picture but short term experiments do not seem significant. We have no opinion about animals other than dogs from actual experience but we feel that short periods during which the red cell and hemoglobin rise above short "normal" periods do not constitute polycythemia as we understand it.

## Methods

The production of this experimental anemia in otherwise normal dogs by bleeding and the routine care of these animals has been described (15). The anemia is continuous usually from maturity (1 year of age) and the basal ration of salmon bread

\* We are indebted to Eli Lilly and Company for aid in conducting this work.

(a complete diet) is fed during all control periods. The anemia level is 6 to 7 gm. hemoglobin and is reached by careful bleeding over 12 to 14 weeks—the normal hemoglobin level being 19 to 20 gm. In this way all reserve stores of hemoglobin building materials are exhausted. These dogs are more susceptible to various infections and are protected by isolation and by vaccination against distemper and dysentery—kept in air conditioned rooms with temperature control. Clinically they are active and normal with excellent appetites at the anemia level which is continued throughout a normal life—8 to 11 years.

The tables below present only the net hemoglobin output although the red and white cell counts, blood volume, and hematocrit are followed and recorded weekly in the histories. The *net hemoglobin output* is obtained very simply by adding together all the hemoglobin removed during the 2 week feeding (copper, iron, cobalt) period plus the following 3 weeks, less the control basal ration hemoglobin production—usually 2 to 3 gm per week. The week following the metal feeding often shows a high hemoglobin output—a carry over which is exhausted during the 2 weeks after period.

The metals are given as various salts but the figures in various tables refer to the metal alone.

#### EXPERIMENTAL OBSERVATIONS

There is a tendency to explain responses like hemoglobin production in anemia as due to an inflow of a substance which has been depleted and therefore lacking for new hemoglobin production. The *iron* effect seems to be a true response to an essential substance which is lacking and required to form new hemoglobin in anemia. *Copper* on the contrary is not lacking but is present more abundantly in the liver of the anemic dog than in the normal dog. Yet copper feeding in modest amounts often does cause an increase in hemoglobin production in these experiments (Table 1). *Amino acids* when fed may likewise cause an increase in hemoglobin production in similar experiments (16). In these dogs there is no lack of protein stores out of which the dog can make plasma protein (9). Moreover, the fasting, anemic dog given abundant iron can produce 100 gm new hemoglobin or more (2). Therefore, we cannot safely assume that this response is due to a *lack* of the given amino acid but rather that the dog can use various amino acids to good purpose in its internal protein metabolism. We prefer to look at these responses to the feeding of copper or amino acids as indications of a change in flow of the protein precursors into the hemoglobin channel—whether this change is associated with enzyme systems or other mechanisms.

Table 1 presents a considerable number of experiments in which various amounts of copper sulfate and tartrate are added to the basal salmon bread ration. This bread contains iron (1.5 mg per 100 gm) as fed. The average daily intake is 300 to 400 gm salmon bread. There may be a response to as

little as 5 mg copper daily. The most uniform response is noted in the experiments with 10 to 15 mg copper daily, an average value of 22 gm hemoglobin output per 2 weeks feeding. With larger doses of copper the responses become more irregular and somewhat less in amount. Responses of less than

TABLE 1

*Copper Added to Basal Ration (Salmon Bread)*

Hemoglobin net output for 2 weeks feeding

Dog. No.	Weight	Copper daily dose	Hb output due to Cu	Control hemoglobin production		
				Fa 40 mg daily	Liver 300 gm. daily	Salmon bread ration
	kg	mg	gm.	gm	gm.	gm.
34-3	15	5	0	52	76	4
32-5	16	5	3	54	97	4
37-23	16	5	54	60	71	4
25-23	14	5	26	50±	82	4
35-2	22	10	26	84	99	8
37-20*	19	10	14	23	46	4
37-83*	14	10	14	59	67	4
27-238	16	13	38	53	—	14
37-23	21	15	15	58	91	16
37-23	19	15	30	60	71	4
32-5	16	15	21	53	112	14
36-12	22	15	18	59	82	4
37-21	18	20	30	61	107	4
30-117	18	20	36	53	92	4
35-4	17	20	5	55†	85	4
40-26	13	20	0	44†	95	4
29-326	18	30	6	74	86	4
32-5	16	30	9	54†	97	4
39-2	18	30	18	44†	103	4
27-241	14	40	20	43	118	14
37-87	19	40	9	61†	72	16
37-22	21	40	5	46†	73	4
37-23	17	40	5	69†	74	6
30-117	17	40	7	53	92	4

\* Bile fistula.

† Iron feeding immediately followed the copper feeding

10 gm. hemoglobin we class as negative. Frequently a copper feeding of 30 to 40 mg daily will give a negative response but subsequently a surplus of hemoglobin may be removed over and above the base line output. This suggests an initial inhibition with subsequent over production in a long continued bread feeding after period. We have observed somewhat similar responses to infection in these anemic dogs—an initial depression followed by periods of over production of hemoglobin (13)

The control hemoglobin production due to salmon bread is about 4 gm per 2 weeks when the iron content of the salmon bread is kept at a minimum of 1.5 mg iron per 100 gm. The higher values recorded in Table 1 (8 to 16 gm hemoglobin) are due to bread containing a higher level of iron—an iron effect in other words.

TABLE 2

*Copper and Iron Given Together*

Hemoglobin net output for 2 weeks feeding

Dog No	Weight	Daily combined dose		Hb output due to Cu + Fe	Control hemoglobin pro duction			Remarks
		Cu + Fe			Fe 40 mg daily	Liver 300 gm daily	Salmon bread ration	
	kg	mg	mg	gm.	gm	gm	gm	
27-238	15	2	21	36	48	—	4	
27-236	17	4	40	73	57	86	10	
27-234	17	4	40	67	72	108	10	
23 1	18	4	40	64	46	107	14	
37-20	17	5	40	18	27	62	4	Bile fistula
34-146	17	5	40	61	49	82	4	Eck fistula
34-146	18	5	400	65	54	82	4	Repeat experiment
29-326	16	5	40	52	48	67	4	
37-20	16	10	40	44	23	62	4	Bile fistula
35-2	22	10	40	84	97	99	8	
34-145	20	10	40	59	54	90	22	
37-83	14	10	40	39	59	67	4	Bile fistula
37-82	17	15	40	55	47*	75	4	
37-23	20	15	40	62	58*	91	8	
35-4	18	20	13	63	48	85	4	
37-21	18	20	40	22	61	73	4	
37-21	17	20	40	78	61	73	4	Repeat experiment
32-5	17	30	40	26	34*	97	20	
37-87	20	40	40	49	56*	72	16	
27-241	14	40	40	67	43	118	20	
29-65	13	40	40	75	59	103	10	
36-12	21	40	40	75	70	85	4	

\* Iron feeding immediately followed copper and iron feeding

Table 2 shows *in general* the negative effect of adding copper to standard doses of iron. The hemoglobin production due to iron alone is very like that due to the same iron dose combined with various amounts of copper. The bile fistula dog presents a subnormal output of hemoglobin due to various food factors including iron (8). Copper causes no unusual effect in the bile fistula dog. The experiments with the Eck fistula (dog 34-146, Table 2) show nothing unexpected. The Eck fistula dog may at times present a subnormal hemo-

globin production in standard anemia experiments. The intake of 400 mg iron daily usually raises the hemoglobin output to the level of the liver feeding (dog 34-146). Occasionally a dog will present responses which are subnormal.

TABLE 3

*Cobalt Added to Basal Ration (Salmon Bread)*

Hemoglobin net output for 2 weeks feeding

Dog. No.	Weight	Cobalt daily dose	Hb output due to cobalt	Control hemoglobin production			
				Fe 40 mg daily		Liver 300 gm. daily	Salmon bread ration
				Before Co	After Co		
	kg	mg	gm.	gm.	gm.	gm.	gm.
34-3	15	5	5	52	34	76	4
34-87	20	10	0	56	90	72	4
37-85	19	10	10	75	55	72	4
32-5	17	20	0	54	111	97	4
37-22	23	20	5	74	71	73	4
30-114	15	25	0	56	—	94	18
36-12	22	30	0	59	70	82	4
35-4	20	40	9	57	61	84	4
37-87	20	40	0	56	40	72	16

TABLE 4

*Cobalt and Iron Given Together*

Hemoglobin net output for 2 weeks feeding.

Dog. No.	Weight	Daily combined dose		Hb output due to Co + Fe	Control Hb output			
		Co	+ Fe		Fe 40 mg. daily		Liver 300 gm. daily	Salmon bread ration
					Before Co	After Co		
	kg.	mg.	mg.	gm.	gm.	gm.	gm.	gm.
29-326	16	10	40	54	50	—	67	4
37-85	19	10	40	31	55	73	72	4
37-22	22	20	40	60	74	56	73	4
35-2	21	20	40	53	49	61	116	8
37-21	16	30	40	26	61	50	75	4
39-1	16	30	40	46	47	44	63	4
39-2	19	40	40	23	44	34	103	4

and this condition usually continues throughout the entire anemic history of the animal (dog 29-326, Table 2). Repeat experiments (dog 37-21, Table 2) indicate that copper may at times modify the iron response in anemia, the first experiment showing a subnormal response and the second experiment showing

a high output of hemoglobin. The experiment with dog 35-4 (iron 13 mg daily given with 20 mg copper, Table 2) shows a high response and the control hemoglobin output due to iron 13 mg daily was only 22 gm hemoglobin—compare response in same dog to 40 mg iron of 48 gm hemoglobin.

Table 3 shows a number of experiments in which various amounts of cobalt are added to the basal ration. The cobalt effect is completely negative in contrast to the copper effect (Table 1). When we compare the response to iron feeding tested before and after the cobalt feeding, we note that the iron response is more irregular after the cobalt experiment in contrast to the iron response before the cobalt. The reason for this irregular response is not clear but there is little doubt that cobalt is slightly toxic to dogs.

Table 4 shows clearly that cobalt added to the usual iron dose does not favor hemoglobin production. On the contrary there appears to be a definite inhibition which can scarcely be due to anything but the cobalt. This inhibitory effect may last over some weeks in certain dogs—for example, dog 39-2, Table 4, given cobalt 40 mg plus iron 40 mg shows an output of hemoglobin of only 23 gm in contrast to iron alone of 44 gm just before the cobalt feeding. Immediately following the cobalt experiment, the standard dose of iron produced 34 gm hemoglobin and immediately following that, the same dose of iron showed an output of 48 gm hemoglobin—that is a late return to normal. One may choose to explain these responses as due to cobalt toxicity.

#### DISCUSSION

Copper at times has a definitely favorable effect upon hemoglobin production in standard anemic dogs—again there is a negative response. Larger doses often are inhibitory, possibly a toxic effect. We have no adequate explanation for these phenomena but recognize the possibility that copper may influence some enzyme system which is related to the construction of the globin or hemoglobin molecules.

The copper effect is attributed by Hart, Elvehjem, and associates (5) to a true deficiency in the diet and body tissues. This may be true for the milk anemias in rats but in the dogs made anemic by bleeding there is no copper deficiency (salmon bread contains at least 1 mg copper in the daily diet). Furthermore, copper analyses (7) show that the liver and spleen in these dogs contain more copper than normal control dogs. In fact, the copper seems to pile up in the liver of these anemic dogs, while the iron store is reduced to minimum levels.

The iron effect is relatively simple and iron is a part of the hemoglobin molecule. Iron given by vein to standard anemic dogs will be returned quantitatively on the basis of the iron contained in hemoglobin—3.4 mg iron returns 1 gm new hemoglobin. Iron absorption is difficult and almost surely this is the most important factor to explain differences in hemoglobin produc-

tion due to iron feeding under these conditions when all reserve iron stores are depleted. Obviously the copper effect differs in many essential respects from the iron effect.

### CONCLUSIONS

Copper added to a standard diet often effects a moderate increase in hemoglobin production in anemia due to blood loss. The copper response is quite irregular in contrast to the iron response. In these dogs there is no lack of copper held in reserve stores (liver and spleen) so the reaction is not related to an actual deficiency of the element. An effect upon enzyme complexes related to globin and hemoglobin production is to be considered.

Cobalt under similar conditions causes no stimulus to hemoglobin production, rather an *inhibitory effect* when more than minimal doses are given. The claim that cobalt causes a polycythemia in dogs receives no support from our experiments.

### BIBLIOGRAPHY

1. Brewer, G., *Am. J. Physiol.*, 1940, 128, 345.
2. Daft, F. S., Robscheit Robbins, F. S., and Whipple, G. H., *J. Biol. Chem.*, 1933, 103, 495.
3. Davis, J. E., *Proc. Soc. Exp. Biol. and Med.*, 1937, 37, 96.
4. Elden, C. A., Sperry, W. M., Robscheit Robbins, F. S., and Whipple, G. H., *J. Biol. Chem.*, 1928, 79, 577.
5. Frost, D. V., Potter, V. R., Elvehjem, C. A., and Hart, E. B., *J. Nutrition*, 1940, 19, 207.
6. Frost, D. V., Spitzer, E. H., Elvehjem, C. A., and Hart, E. B., *Am. J. Physiol.*, 1941, 134, 746.
7. Hahn, P. F., and Fairman, E., *J. Biol. Chem.*, 1936, 113, 161.
8. Hawkins, W. B., Robscheit Robbins, F. S., and Whipple, G. H., *J. Exp. Med.*, 1938, 67, 89.
9. Madden, S. C., and Whipple, G. H., *Physiol. Rev.*, 1940, 20, 194.
10. Mascherpa, P., *Arch. ital. biol.*, 1930, 82, 112.
11. Potter, V. R., Elvehjem, C. A., and Hart, E. B., *J. Biol. Chem.*, 1938, 126, 155.
12. Robscheit Robbins, F. S., and Whipple, G. H., *Am. J. Physiol.*, 1930, 92, 378.
13. Robscheit Robbins, F. S., and Whipple, G. H., *J. Exp. Med.*, 1936, 63, 767.
14. Waltner, K., and Waltner, K., *Klin. Woch.*, 1929, 8, 313.
15. Whipple, G. H., and Robscheit Robbins, F. S., *Am. J. Physiol.*, 1936, 115, 651.
16. Whipple, G. H., and Robscheit Robbins, F. S., *J. Exp. Med.*, 1940, 71, 569.





# RED CELL AND PLASMA RADIOACTIVE COPPER IN NORMAL AND ANEMIC DOGS\*

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Since the demonstration by Hart, Steenhock, Elvehjem, and Waddell and their collaborators (5, 7) that copper plays some essential rôle in the formation of hemoglobin in the copper deficient animal, it seemed of interest to determine if there might be a demonstrable amount of copper taken up by the red blood cell itself during active hematopoietic activity. The availability of radioactive copper<sup>1</sup> in extremely high specific activities allows the use of this material as a tagging agent even though the amount of actual metal taken up is extremely minute.

It is of course necessary to differentiate between copper which, present in the plasma, might exchange with some of the same element normally present in the red cell, and copper which becomes an integral part of the cellular mineral components. The fraction of the circulating red cells in the *normal* dog which are being replaced daily is probably less than 1 per cent of the total (6). On the other hand, under optimum conditions the 10 kilo dog maintained chronically *anemic* by hemorrhage may produce as much as 10 to 15 per cent of its circulating cells in a single day, but an *anemic animal kept on a diet low in iron* may form relatively few red cells (3), perhaps less than the normal dog.

The "half lives" of the radioactive isotopes of copper commonly produced are rather short. One is about 3 hours and the other about 13 hours. The material as obtained from the cyclotron is a mixture of these two. Therefore it is possible to follow the path of copper in an animal for only a few days at the most, unless there is a decided concentration of the element in the tissue under scrutiny, a condition which unfortunately is not the case in red cells. However, if the isotope is fed to normal animals and the extent of its uptake by the red cell determined and likewise the uptake by old and newly forming cells in the anemic animal, some idea of whether or not it is being actually used as a cell component should be determinable. Furthermore, if in two anemic

\* We are indebted to Eli Lilly and Company for aid in conducting this work.

† Fellow of The Rockefeller Foundation.

<sup>1</sup> We are greatly indebted to the Physics Department of the University of Rochester and particularly to Dr. Gerhard Dessauer who specially prepared the radioactive copper used in this work.

made anemic by bleeding over several months time, the dog's red cell hematocrit was 26.1 per cent at the time of feeding and the level of blood hemoglobin was 9 gm. per cent. At this time by standard methods of determination (8), it was found that this dog was producing hemoglobin at the approximate rate of 11 gm. per week. The plasma radio-copper rose rapidly to about 0.27 per cent and remained elevated for about 5 hours after which it dropped until it was 0.1 per cent at the end of 24 hours. The red cell copper in this animal rose to 0.15 per cent in 48 hours.

In the second experiment conducted on this animal the rate of hemoglobin production had been stepped up to about 22 gm. per week by alteration of the diet (iron intake in food). At the time of feeding, the red cell hematocrit was 27 per cent and the hemoglobin level 9.3 gm. per cent. This time the plasma radio-copper rose slightly higher (0.34 per cent) than before but the level was not maintained very long. The red cell copper content did not rise more than half as high (0.08 per cent) as the level in the first experiment.

*Dog 40-179* was a large adult female mongrel shepherd weighing 21 kilos. Before feeding the radio-copper the hematocrit was 25.4 per cent and the hemoglobin level 9.3 gm. per cent, the animal having been kept anemic by hemorrhage for many months. On a diet of hospital scraps this dog was producing 75 gm. of hemoglobin per week at the time of this experiment, this being a high rate of hematopoietic activity for dogs (4). The plasma radio-copper reached only 0.18 per cent of the amount fed per 100 ml. of plasma, this being decidedly lower than any of the other levels attained as seen in Chart A. The 48 hour level of radio-copper in the red cells, however, in this animal was the highest (0.20 per cent) of this small series.

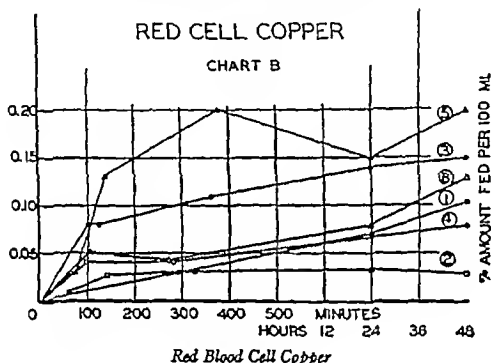
In the second experiment conducted on this animal, the hematocrit at the time of feeding was 19.7 per cent and the hemoglobin level 7.1 gm. The rate of hemoglobin production was reduced considerably from the previous time, however, to 15 gm. per week due to the feeding of a diet low in iron. The plasma radio-copper reached 0.32 per cent in a sharp peak and the red cell copper 0.13 per cent of the amount fed.

#### DISCUSSION

The plasma curves (Chart A) showing the rate of uptake and loss of copper following ingestion are fairly consistent as regards the level reached by the isotope after administration of equal doses. The low level reached by dog 40-179 in the first experiment was first thought to be explained by the weight of this animal, which was about twice that of the others, but in the second experiment the level reached was about the same as occurred in the smaller dogs.

The uptake of radio-copper in the red cells in the course of 2 days following feeding is to some degree equivocal. Dog 40-133 having a normal blood picture took up the least of the metal. However, the other normal animal accumulated about the same amount of copper in the cells as did the anemic animals in all of the experiments with the exception of dog 40-179, in the first experiment on that animal, when the rate of hemoglobin formation was very high (Chart B).

The fact that the plasma copper in the first experiment on dog 40-179 never reached the level it did in the other experiment on this animal, when the rate of hematopoietic activity was much lower, or the level reached in the other dogs, normal and anemic, suggests that the copper might have been withdrawn at a greater rate. Furthermore, in this animal the level of the isotope in the red cells increased at a markedly higher rate than in any of the others and reached a higher final value. This might be construed as evidence that some of the copper was being used in red cell elaboration but is not borne out by the observations on dog 40-149. In the latter case, the red cell level of copper reached



- (1) 39-320, normal.
- (2), 40-133, normal.
- (3), 40-149 anemic, hemoglobin production 11 gm. per week.
- (4), 40-149 anemic, hemoglobin production 22 gm. per week.
- (5), 40-179, anemic, hemoglobin production 75 gm. per week.
- (6), 40-179, anemic, hemoglobin production 15 gm. per week.

in 2 days was higher in the experiment during which the rate of hemoglobin regeneration was lower

With such a small series of experiments it is not safe to draw any sweeping conclusions, but there is some indication that where hemopoietic activity is greater than normal, the uptake of the small traces of radio-copper by the red cell may be increased. If the whole picture is one dependent on the adsorption of the metal on the red cell, the greater amount of copper present in the circulation of the anemic animals might be related to a greater affinity of the new cell forms due possibly to differences in the surface makeup. As in the case for the

plasma, further studies<sup>2</sup> on the red cell copper are indicated to determine the nature of the adsorption isotherm at various concentrations of copper

#### SUMMARY

Following ingestion of radioactive copper by the dog, the metal appears quickly in the plasma, the concentration reaching its peak in from 2 to 5 hours, after which it falls abruptly. Demonstrable amounts are still present after 2 days. The radioactive copper likewise appears rapidly in the circulating red blood cells, and there is a slow but gradual increase in its concentration over a 2 day period.

It is suggested by the data that in the animals in which hematopoietic activity is accelerated the uptake of radio-copper is somewhat more extensive. The possibility that this is due to greater adsorption by the new red cells in these instances is not ruled out.

#### BIBLIOGRAPHY

- 1 Bale, W F, Haven, F L, and Le Fevre, M, *Rev Scient Instr*, 1939, 10, 193
- 2 Hahn, P F, Bale, W F, Lawrence, E O, and Whipple, G H., *J Exp Med*, 1939, 69, 739
- 3 Hahn, P F, and Whipple, G H., *Am J Med Sc*, 1936, 191, 24
- 4 Hahn, P F, and Whipple, G H., *J Exp Med*, 1939, 69, 315
- 5 Hart, E B, Steenbock, H, Elvehjem, C A, and Waddell, J, *J Biol Chem*, 1925, 65, 67
- 6 Hawkins, W B, and Whipple, G H., *Am J Physiol*, 1938, 122, 418
- 7 Schultze, M O, *Physiol Rev*, 1940, 20, 37
- 8 Whipple, G H., and Robschert-Robbins, F S, *Am J Physiol*, 1936, 115, 651

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<sup>2</sup>Dr Yoshikawa's stay being interrupted, it was considered advisable to put on record the observations as they stand. It is hoped to extend these experiments at a later date.

## ANTIBODY RESPONSE OF HUMAN BEINGS FOLLOWING VACCINATION WITH INFLUENZA VIRUSES

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A number of investigators (1-7) have reported the results of studies on the antibody response of human beings following the parenteral administration of various preparations containing influenza virus. With one exception (6) these earlier investigations were carried out on relatively small groups of individuals since the difficulty of examining large numbers of sera by means of the neutralization test in mice was often a limiting factor. Most workers used a single variety of vaccine, although Horsfall, Lennette, and Rickard (5) investigated a number of different preparations in small groups of volunteers. Despite the efforts which have been expended in the study of influenza virus vaccines in human beings, there is at present relatively little known concerning the factors which influence the specific antigenicity of the various kinds of vaccine which can be prepared with this agent.

While extensive work has been done on the antibody response of experimental animals vaccinated with various preparations of influenza virus, the results obtained in such studies are not necessarily applicable to man. Most human beings, unlike most experimental animals, have had at least one contact with influenza virus, and these previous infective experiences are probably one of the factors which condition their responses to vaccination with the virus in an unpredictable manner. Since man is the subject whom it is desired ultimately to protect against attacks of influenza, it seems apparent that direct testing in human beings facilitates the evaluation of the effectiveness of various kinds of vaccines.

Previous workers (1-7) have found that there was marked individual variation in the antibody response of human beings to any one variety of influenza virus vaccine. Because of the individual differences in response it seemed necessary, in order to obtain significant data for the comparison of the specific antigenicity of different virus preparations in man, to use large numbers of individuals in the study of each vaccine.

With the demonstration that influenza viruses agglutinate chicken red blood corpuscles, and that this capacity is specifically inhibited by immune serum (8), a new and relatively simple *in vitro* test for the determination of influenza antibodies became available (9). As has been shown, the titers of influenza

antibodies in normal human sera, as determined by this method, very closely paralleled the titers obtained by means of the virus neutralization test in mice. This parallelism also obtained with sera from human beings who had been vaccinated recently with influenza virus. Furthermore the test was sensitive to relatively small changes in antibody concentration, and the end points obtained had a high degree of reproducibility. Because this method could be applied relatively easily to large numbers of sera it became possible to undertake a large-scale study of the antibody response to vaccination with influenza viruses in human beings.

The experiments in the present paper were designed to explore several questions related to human vaccination with influenza viruses: (a) How much variation in individual antibody response occurs in a large group which has been given a single type of vaccine, and how does the individual response vary with the prevaccination antibody level? (b) What are the relative merits as specific antigens of whole chick embryo vaccines prepared with and without the X strain of distemper virus? (c) How does the antibody response vary with dosage of influenza virus? (d) How does active virus compare with inactive virus as an antigen? (e) What is the effect of increasing the inert protein content of the vaccine? (f) How rapidly do individuals lose the additional antibodies produced following vaccination? (g) How closely does the antibody response to influenza A virus parallel that to influenza B virus under various conditions?

Allantoic fluid from infected chick embryos has been shown to be an excellent source of influenza viruses (10-12) and has been used as the source of material for most of these experiments. In addition to a high virus titer, allantoic fluid contains relatively little non-virus protein. Furthermore the virus present in such fluids can be concentrated readily by several methods, permitting the administration of much larger amounts of virus than heretofore.

### *Methods*

Inasmuch as these studies were designed to compare the specific antigenicity of vaccines modified in one factor only, it was essential that the basic source material be the same for all preparations. For this purpose two large pools of infected allantoic fluid were prepared, one containing the PR8 strain of influenza A virus (13) and the other the Lee strain of influenza B virus (14). Furthermore to insure uniformity the various vaccines were prepared at the same time with the exception of 53, 54, and 64, which were handled separately as will be explained in the text. Usually, equal amounts of the two allantoic fluid pools which had been treated similarly were combined to make the final preparation. Chick embryo passage derivatives of the mouse-virulent PR8 and Lee strains were the only viruses used throughout this work, except in vaccine 64 which contained the W S strain (15) in addition and vaccine 54 which was prepared with a mixture of the PR8 strain and the X strain of distemper virus (16).

*Preparation of Allantoic Fluid Pools Used for Vaccines*—To prepare the basic allantoic fluid pools 11-day old chick embryos were used. The embryos were inoculated with 0.1 cc. of infected allantoic fluid (diluted to  $10^{-3}$  in saline) through a small puncture in the shell over the chorioallantoic membrane. No attempt was made to drop this membrane. After 2 days incubation at  $37^{\circ}\text{C}$  blood-free allantoic fluid was removed under sterile conditions as described in a previous report (9). A portion of the fluid from each egg was cultured in blood broth, and while the results of culture were being determined, the remainder of the fluids from individual eggs was stored frozen at  $-72^{\circ}\text{C}$ . All contaminated fluids were discarded and the sterile fluids were pooled. The combined sterile fluids were clarified by low-speed centrifugation, and the sediments were discarded. The pools were then stored at  $-10^{\circ}\text{C}$ . until the various vaccines were prepared. Each pool was titered in mice, after it had been diluted serially in steps of  $10^{-0.4}$ , and the 50 per cent mortality end point was determined. About 3,500 cc. of PR8 and 2,000 cc. of Lee fluids were prepared.

The individual vaccines (except 53, 54, and 64) were all made from these pools on the same day. The technique used for each preparation will be described in the text. All vaccines except 61 and 64 were frozen and dried (17) and were rehydrated with distilled water just before use.

*Method of Vaccination*.—In all cases the vaccinated subjects were patients in state hospitals. Their ages varied from 15 to 60 years, and they were predominantly males. In most instances 150 individuals were inoculated with each vaccine. A number of different vaccines were given on each ward in order to rule out possible variation in response from one group to another. A blood specimen was taken from each individual just before vaccination and another 2 weeks following vaccination. The sera were separated and stored at  $4^{\circ}\text{C}$ . until they were tested for antibody titer. Some of the subjects were bled also at 6 weeks, 9 weeks, and 5 months following vaccination.

*Determination of Antibody Titer in Serum*—All of the human sera, both pre- and postvaccination specimens, were tested for their capacity to inhibit the agglutination of chicken red cells by the PR8 strain and the Lee strain of influenza virus. The virus suspensions used for these tests were prepared in the same manner as the allantoic fluid pools used for vaccination. Large quantities of each virus were prepared at one time. Each pool of test virus was distributed in small amounts (2 to 25 cc.) in lusteroid tubes, which were then stored at  $-72^{\circ}\text{C}$  until used. Two such pools of influenza A virus and two of influenza B virus were necessary to complete the serum titrations.

The chicken red cells used for these tests were obtained from a local slaughterhouse. After the cervical vessels of the chickens were severed the blood was collected in a flask containing a liter of 2 per cent sodium citrate solution. Two liters of chicken blood were collected at one time. The cells were washed three times in saline and after the final washing were centrifuged at 900 R.P.M. for 11 minutes. The packed cells were stored at  $4^{\circ}\text{C}$ . and were diluted just before use with 49 volumes of saline. Red cells were not used more than 1 week after being obtained.

The sera to be tested were inactivated by heating at  $56^{\circ}\text{C}$ . for 30 minutes. Serial dilutions were then made in saline, using twofold steps. To  $\frac{1}{2}$  cc. of each serum dilution was added  $\frac{1}{2}$  cc. of virus dilution, and to this mixture was added 1 cc. of a 2 per cent suspension of chicken red cells. The red cells were added with an automatic

antibodies in normal human sera, as determined by this method, very closely paralleled the titers obtained by means of the virus neutralization test in mice. This parallelism also obtained with sera from human beings who had been vaccinated recently with influenza virus. Furthermore the test was sensitive to relatively small changes in antibody concentration, and the end points obtained had a high degree of reproducibility. Because this method could be applied relatively easily to large numbers of sera it became possible to undertake a large-scale study of the antibody response to vaccination with influenza viruses in human beings.

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The sera to be tested were inactivated by heating at  $56^{\circ}\text{C}$ . for 30 minutes. Serial dilutions were then made in saline, using twofold steps. To  $\frac{1}{2}$  cc. of each serum dilution was added  $\frac{1}{2}$  cc. of virus dilution, and to this mixture was added 1 cc. of a 2 per cent suspension of chicken red cells. The red cells were added with an automatic

pipetting machine which delivered the cells with such force that adequate mixing took place at once. The mixtures were allowed to stand at room temperature for  $1\frac{1}{4}$  hours before readings were made. This was found to give slightly sharper end points than readings made at 1 hour.

The degree of red cell agglutination was read by comparing the densities of the supernatant fluids in the various serum dilutions with the densities of standard red cell suspensions. The red cell concentrations of these standards were 1.0, 0.87, 0.75, 0.67, 0.50, 0.37, and 0.25 per cent, and they were made up in each instance from the same suspension that was used for testing the sera. The end point of a titration was considered to be the tube which had a density falling between that of the 0.67 per cent and the 0.50 per cent standard. Frequently, however, the transition from complete inhibition to maximum agglutination was such that there was no tube with a density falling within this range. The end point then was considered to be halfway between the tube of density higher than 0.67 per cent and the adjacent tube of density lower than 0.50 per cent. Serum titers were expressed as the reciprocal of the dilution of serum in the end point tube.

The same method of determining end points was used to standardize the virus preparations against which the sera were tested. For this measurement twofold dilutions of virus suspension were made in saline. To 1 cc. of each dilution was added 1 cc. of 2 per cent chicken red cells, and the end points were read after the mixtures had stood for  $1\frac{1}{4}$  hours. Four times the concentration of virus capable of producing the end point described above was used for testing the human sera. This usually resulted in the use of a final concentration of 1/64 for the PR8 strain and 1/32 for the Lee strain. This amount of virus generally produced a residual red cell density of 0.25 per cent or less in the supernatant of the virus control tube.

Since slight day-to-day fluctuations were known to occur in the degree of agglutination obtained with a given dilution of virus suspension, the following controls were set up to determine the amount of this variation. An agglutination titration of each virus was set up with every series of antibody determinations. A more important control, however, was the titration of standard immune ferret sera. With each series of determinations three duplicate titrations of standard sera against each virus were set up at the beginning, middle, and end of the test. Usually there was little or no difference between the results obtained with these standards, both in the same series and from one series to the next. When the controls indicated that the level of the test was markedly altered, the experimental results were corrected to a degree indicated by the deviation of the controls.

A further method for eliminating errors due to unpredictable fluctuations was to distribute the sera obtained from individuals given a single vaccine over many series of determinations so that each series usually contained some sera from individuals given each of the vaccines. In this way the antibody responses produced by all the vaccines were submitted to an equal amount of variation in testing. The prevaccination and postvaccination sera from each individual were always tested in the same run. Each run consisted of approximately 250 titrations, or 125 pairs of pre- and postvaccination sera.

In addition to the sera from the vaccinated individuals, acute and convalescent phase specimens from 232 cases of influenza A were tested at the same time and in

the same way. This was done in order to establish by the same technique the levels of antibody obtained following infection with influenza virus. In general, the acute sera were taken within the first 4 days of the illness and the convalescent sera about 2 weeks after the onset. All of these sera came from institutional epidemics in Alabama in 1941, and had been tested previously by the complement fixation or neutralization test and showed at least a fourfold rise in antibody titer by one technique or by both.

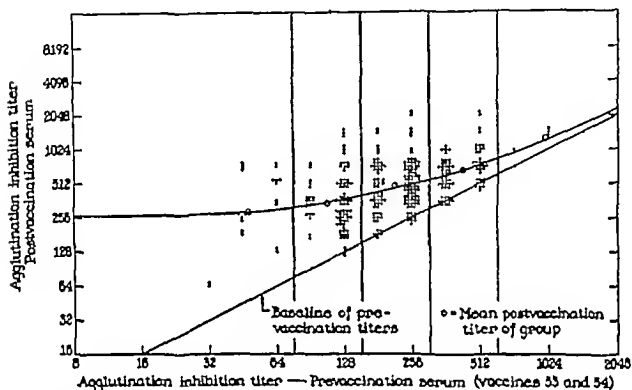


FIG. 1. Antibody response against the PR8 strain at 2 weeks of 400 human beings who were given formalinized chick embryo influenza vaccines 53 and 54.

#### EXPERIMENTAL

*Antibody Response of the Individual to Vaccination*—Before comparing the average antibody responses of groups of human subjects to various vaccines, it was necessary to determine first the individual variations in response to one type of preparation.

Fig. 1 is a spot chart of the antibody response of 400 individuals 2 weeks after the subcutaneous injection of formalinized preparations of chick embryo containing influenza A virus (vaccines 53 and 54). The details of the preparation of these vaccines will be given below. Each dot on the chart represents the prevaccination and the postvaccination antibody levels of one individual against the PR8 strain of virus. The scale for both the pre- and the postvaccination levels is logarithmic. The entire group of subjects was divided into subgroups on the basis of their prevaccination titers, and the geometric mean of the postvaccination levels of each subgroup was determined. These mean values are represented by open circles in Fig. 1.

Since all the vaccines which were tested gave this same type of distribution in antibody response, certain generalities concerning the results shown in Fig 1 may be of significance in the problem of vaccination against influenza in general. The most obvious finding was the enormous variation in antibody response which occurred even among those individuals who possessed similar prevaccination antibody titers. A considerable number failed to show a sufficient increase in antibody to be detected by this test, and the proportion of non-reactors was significantly greater among those individuals with high prevaccination levels than among those with low levels.

The curved line in Fig 1 represents the level that would have been obtained if an equal amount of antibody had been added to each prevaccination specimen. Since this curve closely fits the geometric means of the postvaccination levels found experimentally, it follows that the average actual antibody production as opposed to increase in titer in each of these subgroups was nearly the same, regardless of the prevaccination antibody level.

From a consideration of the foregoing results it was decided to compare different vaccines in terms of the geometric mean antibody level obtained 2 weeks following vaccination. A significant comparison between mean levels can be made only if the prevaccination titers are nearly the same in the groups under consideration. This method is in contrast to that used by Horsfall, Lennette, and Rickard (5) who selected individuals of low antibody titer and based their conclusions mainly on the incremental increases (times rise) obtained in the low antibody group. As this study was based on unselected groups, the incremental rises observed were lower than those found by Horsfall, Lennette, and Rickard. In addition, the method of testing which has been used in this study gives results which show smaller differences between the antibody titers of sera than are shown either by serum neutralization end points in mice or by the calculation of neutralizing capacities. This in no way invalidates the relationship between the two tests previously demonstrated (9) but merely means that the range of titers by *in vitro* measurements are expressed on a compressed scale.

In this study the geometric mean has been used for comparison of different vaccines because of the ease of statistical handling. If influenza antibody titers are plotted on a geometric scale, they give fairly symmetrical probability curves (Fig 2), and the geometric mean of the titers is at or near the peak of the curve. If the same titers are plotted on an arithmetic scale, however, the arithmetic mean is not at the peak of the curve, and the value of this mean is greatly affected by the presence or absence of a few sera of very high titer. The use of the arithmetic mean would involve the employment of extremely large groups in order to obtain significant comparisons. It should be emphasized that even when a large number of subjects are used, the variation in individual human response is so great that only rather large differences in the geometric mean levels have any statistical significance.

*The Effect of the X Strain of Distemper Virus on the Antigenicity of Influenza Vaccines*—Horsfall, Lennette, and Rickard (5) reported a series of vaccination studies in human beings using a number of different virus preparations. From their results they concluded that a preparation of formalinized chick embryo virus prepared by inoculating embryos with a mixture of the PR8 strain of influenza A virus and the X strain of distemper virus had greater antigenicity

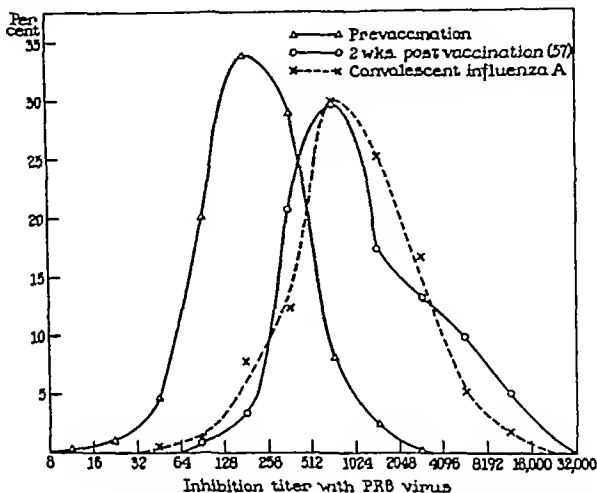


FIG. 2. Curves showing the distribution of antibody titers against influenza A among a normal population, a recently vaccinated population, and a group of convalescent cases of influenza A.

than a similar preparation made by inoculating the PR8 strain alone. However, during the past year, further observations in this laboratory have not borne out these conclusions. Since it is now known that great individual variation occurs in the antibody response to vaccination, a review of the evidence on which the comparison between these vaccines was made suggests that the results may have been due to errors introduced by random sampling. It was decided, therefore, to repeat these experiments on a larger scale.

*Vaccine 53*—Eleven-day old white Leghorn embryos were inoculated with 0.05 cc. of a  $10^{-3}$  dilution of allantoic fluid containing the PR8 strain plus 0.05 cc. of saline.

The inoculations were made directly into the embryo. After 48 hours incubation at 37°C, the embryos were removed, homogenized in a Waring mixer, and diluted to 20 per cent concentration with saline. The sediment was removed by centrifugation and discarded. Formalin was added to a concentration of 1/4,000 formaldehyde. After standing for 48 hours at 4°C the suspension was frozen and dried. The active embryo suspension gave a 50 per cent mortality titer of  $10^{-5.3}$  in mice. The finished vaccine was not infectious for mice when 0.05 cc. of a 20 per cent suspension was given intranasally. The vaccine was rehydrated to its former volume with distilled water just before use, and each subject was given 1 cc. of this 20 per cent suspension subcutaneously. This was the equivalent of 632,000 fifty per cent mouse mortality doses of active virus.

*Vaccine 54*—The preparation was identical with that of vaccine 53 except for the inoculum used for the embryos. The inoculum contained 0.05 cc. of a  $10^{-3}$  dilution of allantoic fluid containing the PR8 strain and 0.05 cc. of a  $10^{-3}$  dilution of ground ferret spleen. The spleen was obtained from a ferret that had been infected with the X strain of distemper virus. Ferrets, when given 1 cc. of a  $10^{-4}$  dilution of this spleen suspension, came down with typical distemper. The 50 per cent mouse mortality titer of this vaccine was  $10^{-5.1}$ , and like vaccine 53, the finished preparation was non-infectious for mice. Individuals who were given 1 cc. of this vaccine subcutaneously received the equivalent of 500,000 fifty per cent mouse mortality doses.

While the technique of preparing these vaccines was not identical with that of Horsfall, Lennette, and Rickard, the differences in technique are not considered important. Furthermore the augmentation of antibody level produced by vaccines 53 and 54 was of the same order of magnitude as that observed by Horsfall, Lennette, Rickard, and Hirst (6) in a later and more extended series of vaccinations with the complex material.

The antibody response to the PR8 strain produced by these two vaccines is shown in Table I. It will be seen that both the mean prevaccination levels and the mean postvaccination levels of the two groups were nearly the same. It is probable, therefore, that the addition of the X strain of distemper virus did not significantly enhance the antigenicity of influenza A virus.

Although these two vaccines did not contain influenza B virus, it was decided to test all the sera against the Lee strain of this virus. The results, which are also shown in Table I, emphasize the complete lack of antigenic relationship between these strains of influenza A and influenza B viruses. They also show that the injection of chick embryo material, in the form of a vaccine, did not give rise to antibodies which seriously interfered with the specificity of the *in vitro* test, even though a chick embryo source was used for the test virus.

*Effect of the Amount of Virus Injected upon the Antibody Response*—Since subcutaneously administered virus is not known to multiply in the human organism, the amount of virus given should have a pronounced effect upon the magnitude of the antibody response obtained, at least over a considerable range of virus concentrations. The following experiment was an attempt to

determine how much the response varied when different amounts of virus were given

**Vaccine 56**—This vaccine was prepared by mixing equal volumes of the PR8 and Lee allantoic fluid pools. The mixture was frozen and dried and rehydrated just before use. Each individual received subcutaneously 0.1 cc. of the mixed fluids diluted to a volume of 1 cc. with saline. This was the equivalent of 36,200 fifty per cent mortality doses of the PR8 strain and 1,000 fifty per cent mortality doses of the Lee strain per person. The viruses were active when injected.

**Vaccine 55**—This preparation was made in the same way as vaccine 56, but each individual received subcutaneously 1 cc. of the mixed fluids or 362,000 fifty per cent

TABLE I

*Effect of the X Strain of Distemper Virus on the Antigenicity of a Vaccine Containing Influenza A Virus*

Vaccine No.	Preparation of vaccine	Influenza A virus (PR8 strain)			Influenza B virus (Lee strain)			No. vaccinated
		No. 50 per cent mouse mortality doses per person	Mean preinactivation and body titer	Mean 2 wk. post vaccination antibody titer	No. 50 per cent mouse mortality doses per person	Mean preinactivation antibody titer	Mean 2 wk. post vaccination antibody titer	
53	Formalinized whole chick embryo, inoculated with PR8 only	632,000	205	477	0	79	84	196
54	Formalinized whole chick embryo, inoculated with PR8 and $\frac{1}{2}$ strain of distemper virus	500,000	205	486	0	77	84	201

\* Before inactivation

mortality doses of the PR8 strain and 10,000 fifty per cent lethal doses of the Lee strain.

**Vaccine 57**—A large amount of PR8 allantoic fluid was centrifuged at 11,000 R.P.M. for 2 hours, and the sediment was resuspended in a small amount of the supernatant fluid. Over 95 per cent of the virus was recovered in the sediment. A somewhat smaller amount of Lee allantoic fluid was likewise centrifuged and the sediment resuspended in a small amount of supernatant. These resuspended sediments were combined, frozen and dried. The mixture was resuspended in saline at the time of administration and given subcutaneously in a volume of 1 cc. Each individual was given that quantity of virus originally present in 5 cc. of PR8 fluid and 2 cc. of Lee fluid, or 3,620,000 fifty per cent mortality doses of the PR8 strain and 40,000 fifty per cent mortality doses of the Lee strain. This represents ten times the amount of influenza A virus and four times the amount of influenza B virus in vaccine 55. As with vaccines 55 and 56, the viruses were injected in the active state.

*Vaccine 64*—Although this preparation was made and given to human beings prior to any other vaccine reported in this paper, the sera were tested simultaneously with those from other vaccine groups. The vaccine was prepared in essentially the same manner as vaccine 57. Infected allantoic fluid was centrifuged at high speed and the sediments were pooled. The vaccine was not dried before use but was kept at  $-72^{\circ}\text{C}$  until administered. Allantoic fluid containing the W S strain was included, as well as preparations of the PR8 and Lee strains. The amounts of virus given were calculated from mouse titrations on the concentrated suspensions. Each subject received subcutaneously 190,000,000 fifty per cent mortality doses of the W S strain, 24,000,000 doses of the PR8 strain, and 1,000,000 doses of the Lee strain. These quantities were obtained by concentrating 24 cc of PR8 fluid, 10 cc. of W S, and 5 cc of Lee allantoic fluid.

TABLE II

*Variation in the Antibody Response When Different Amounts of Influenza Viruses Were Used in Vaccines*

Vaccine No	Influenza A virus (PR8 strain)			Influenza B virus (Lee strain)			No vaccinated
	No. 50 per cent mouse mortality doses per person	Mean prevaccination antibody titer	Mean 2 wk postvaccination antibody titer	No. 50 per cent mouse mortality doses per person	Mean prevaccination antibody titer	Mean 2 wk postvaccination antibody titer	
56	36,200	183	369	1,000	85	183	145
55	362,000	168	461	10,000	87	276	146
57	3,620,000	163	935	40,000	84	443	120
64	PR8 = 24,000,000 W S = 190,000,000	103	1,100	1,000,000	57	444	43
*	Influenza A	104	865		90	84	232

\* Cases of clinical infection included for comparison

*Influenza A Cases*—In this experiment were included the 232 cases of influenza A previously mentioned. Each case had previously been diagnosed as influenza A on the basis of a fourfold or greater rise in antibody titer, as determined by complement fixation or neutralization tests.

The results of antibody titrations on sera obtained from these groups are shown in Table II. With vaccines 55, 56, and 57 the antibody response definitely increased with each tenfold increase in the amount of virus given. This is true of the response to both the PR8 and the Lee strains. However, the degree of change of antibody titer is of a considerably smaller magnitude than the differences in the amount of virus given.

With vaccine 57, the levels of antibody obtained were of the same order of magnitude as those which occurred following actual infection. A graphic comparison of these two groups is given in Fig 2. It will be observed that not only



were the mean antibody levels similar but the distribution of titers was very nearly the same. It should be pointed out, however, that the levels in the convalescent group were measured with a heterologous strain of virus, while the sera from group 57 were titrated with a homologous strain of virus. This might tend to cause the infected group to show lower titers than otherwise. On the other hand, the cases of influenza A were arbitrarily selected on the basis of a fourfold antibody rise. If the lesser antibody responses among the clinical cases had been included in this group, the mean final titer would have been 655. It seems unlikely that it will be possible to obtain, by vaccination, antibody levels which are greatly higher than those following actual infection by influenza viruses.

While vaccine 64 was given to a relatively small group, and the material used was not strictly comparable to that used in other experiments, the results are included as another example of the response obtained with a very large amount of virus. In terms of lethal doses of both the PR8 and the Lee strains injected, vaccine 64 was considerably superior to vaccine 57. In spite of this, the antibody response was of almost the same order of magnitude with the two preparations. This strongly suggests that further increases in the amount of virus injected at one time probably would not give a greatly improved antibody response. The large number of lethal doses of W S virus given may be misleading and was probably not an indication of the relative amount of antigen given.

*Relative Antigenicity of Active Versus Inactive Virus*—In the following experiment a comparison was made between the antigenicity of active influenza viruses (the PR8 and Lee strains) and preparations of the same viruses which had been inactivated by heat or formalin. Since freezing and drying also inactivate influenza virus to some extent, a preparation was included in this experiment in which the vaccine was kept frozen at  $-72^{\circ}\text{C}$ . but was not dried.

All of the vaccines in this group were made from the allantoic fluid pools. Each individual received in one subcutaneous injection  $\frac{1}{2}$  cc. of the PR8 pool and  $\frac{1}{2}$  cc. of the Lee pool. The 50 per cent mortality end point of the PR8 pool was  $10^{-4.4}$  and of the Lee pool was  $10^{-3.9}$ . Therefore, each individual received the equivalent of 362,000 fifty per cent mortality doses of influenza A virus and 10,000 fifty per cent mortality doses of influenza B virus.

*Vaccine 55*—This preparation has been described previously. The virus was frozen and dried without inactivation. Titration of the finished vaccine, however, showed a tenfold drop in mortality titer due to drying.

*Vaccine 59*—After equal quantities of the PR8 and Lee pools were mixed formalin was added to a final concentration of 0.2 per cent formaldehyde. The mixture stood at  $4^{\circ}\text{C}$ . overnight and was frozen and dried the following day. The formalinized mixture gave no evidence of infectivity when administered intranasally in full concentration to mice. Each subject received subcutaneously 1 cc. of the pooled fluids.

*Vaccine 60*—Equal amounts of the PR8 and Lee pools were combined, and the

mixture was heated at 56°C in a water bath for 15 minutes. The heated preparation gave no evidence of infectivity when administered to mice intranasally in full concentration. The vaccine was frozen and dried immediately after heating. Each subject received subcutaneously 1 cc. of the mixture.

*Vaccine 61*—The preparation was the same as for vaccine 55 except that it was stored at -72°C until administered and was not dried. There was no significant loss of infectivity for mice between the time of preparation and the time when it was given to human beings.

TABLE III

*Effect of Inactivation of Influenza Viruses on Antigenicity in Human Beings*

Vaccine No	Preparation of vaccine	Influenza A virus (PR8 strain)			Influenza B virus (Lee strain)			No vaccinated
		No. 50 per cent mouse mortality doses per person	Mean prevaccination anti-body titer	Mean 2 wk. post vaccination anti-body titer	No. 50 per cent mouse mortality doses per person	Mean prevaccination anti-body titer	Mean 2 wk. post vaccination anti-body titer	
55	Active virus in allantoic fluid, frozen and dried	362,000	168	461	10,000	87	276	146
59	Virus in allantoic fluid inactivated with formalin	362,000*	183	429	10,000*	87	293	143
60	Virus in allantoic fluid inactivated by heating	362,000*	163	515	10,000*	90	278	144
61	Active virus in allantoic fluid, kept frozen, not dried	362,000	136	479	10,000	86	328	146

\* Before inactivation

The results of this experiment are recorded in Table III. Against both influenza A virus and influenza B virus the mean postvaccination antibody titers showed only negligible variation among the vaccines used. Such variation as occurred was not statistically significant. The same results were obtained with vaccine 55 where 90 per cent of the virus activity was lost through drying, yet the effect was not significantly different from vaccine 61, which had an unaltered mouse virulence at the time of administration. In view of the fact that the previous experiment showed a significant drop in antibody response when the injected antigen was reduced 90 per cent (vaccines 55 and 56), it seems evident that the virus which is inactivated during desiccation is not significantly altered as an antigen.

*Effect of Adding Infected Chick Embryos to Allantoic Fluid Vaccines*—In order to determine the effect of increasing the protein content of a vaccine, it

was decided to test preparations in which infected chick embryos were added to infected allantoic fluid. Since the chick embryos used for this purpose had the same virus titer as the fluids to which they were added, the effect would seem to be limited to increasing the proportion of non virus material in an allantoic fluid vaccine.

*Vaccine 62*—For this experiment chick embryos were used from the same eggs from which the allantoic fluid pools were prepared. Embryos infected with the PR8 strain were prepared separately from those containing the Lee strain. The chick embryos were ground in a Waring mixer, after the addition of enough of the allantoic fluid pool to make a 20 per cent chick embryo suspension. The sediment was removed by low speed centrifugation and equal quantities of the PR8 and Lee suspensions were mixed, frozen, and dried. The vaccine was rehydrated just before use, and each subject received 1 cc. subcutaneously of the 20 per cent chick embryo suspension. The 50 per cent mouse mortality titers of both the PR8 and the Lee suspensions were the same as the respective allantoic fluid pools. Each individual received 362,000 fifty per cent mouse mortality doses of the PR8 strain and 10,000 fifty per cent mouse mortality doses of the Lee strain.

*Vaccine 63*—This was prepared in an identical manner with vaccine 62 except that after mixing the two virus preparations formalin was added to a final concentration of 0.2 per cent formaldehyde, and the mixture stood at 4°C overnight before freezing and drying. The formalinized mixture was not infective for mice when given intra nasally in full concentration.

The results of vaccination with these preparations are shown in Table IV. For purposes of comparison the results obtained with vaccine 55 prepared from active allantoic fluid alone are included. A comparison of the mean post vaccination antibody titers shows that the addition of whole chick embryo definitely enhanced the antigenicity of both influenza A and B viruses, when the viruses were in the active state. However, when the preparation was formalinized the antibody response was reduced to levels similar to those obtained with active allantoic fluid (vaccine 55) and with formalinized chick embryo alone (vaccines 53 and 54).

Since the mouse mortality titers of the viruses in vaccines 55 and 62 were similar, it is necessary to assume either that the added chick embryo suspension itself has some stimulatory effect or, as seems more likely, that the mouse titration does not accurately measure all of the virus in the chick embryo suspensions. It seems possible that such suspensions contain considerable quantities of non infective but nevertheless antigenic virus. Why this additional antigenicity should disappear after formalinization is not clear.

Since no preparation was tested to which uninfected chick embryo tissue had been added, the precise effect of inert proteins themselves in influenza virus vaccines was not determined. It is fairly clear, however, from a comparison of the results obtained with vaccines 53, 54, 55, 62, and 63 that the

relatively low concentration of inert protein in allantoic fluid has little, if any, beneficial effect upon the antigenicity of the virus present therein

*Rate of Disappearance of Antibody Following Vaccination*—The groups that received vaccines 55 and 57 were bled 2 months following their vaccination. The smaller group that received vaccine 64 was bled 6 weeks and 5 months following vaccination. These sera were tested with the same lots of virus used

TABLE IV

*Effect of Added Ground Chick Embryo Tissue on the Antigenicity of Influenza Virus*

Vaccine No	Preparation of vaccine	Influenza A virus (PR8 strain)			Influenza B virus (Lee strain)			No vaccinated
		No. 50 per cent mouse mortality doses per person	Mean prevaccination antibody titer	Mean 2 wk. post-vaccination antibody titer	No. 50 per cent mouse mortality doses per person	Mean prevaccination antibody titer	Mean 2 wk. post-vaccination antibody titer	
62	20 per cent infected chick embryo diluted with infected allantoic fluid. Active virus	362,000	165	658	10,000	97	396	144
63	Same as vaccine 62 except preparation was formalinized	362,000*	166	477	10,000*	90	253	146
55	Active virus in allantoic fluid alone	362,000	168	461	10,000	87	276	146

\* Before inactivation

TABLE V

*Change in Mean Antibody Levels at Different Lengths of Time after Vaccination*

Vaccine No	Antibody titer against influenza A virus (PR8 strain)					Antibody titer against influenza B virus (Lee strain)				
	Prevaccination	2 wk.	6-wk.	9-wk.	22 wk.	Prevaccination	2 wk.	6-wk.	9-wk.	22 wk.
55	168	461		315		87	276		213	
57	163	935		537		83	443		300	
64	103	1100	540		345	57	444	188		136

for the other titrations, and the 2-week postvaccination sera were retested at the same time. The mean antibody levels are shown in Table V. The prevaccination and the 2-week postvaccination titers are included for comparison.

There was a rapid and considerable drop in antibody levels after the peak at the 2-week period. While the loss in antibody was greater with vaccine 57 than with vaccine 55 at 9 weeks, the former group still had a higher titer at that time. Even at 22 weeks the group that had received vaccine 64 possessed anti-

body levels considerably above their initial level. When individual responses were examined, it was seen that the incremental drop in titer in all individuals was fairly uniform, *i.e.*, those who had responded poorly subsequently lost about the same percentage of their added antibody as did those who had responded well.

#### DISCUSSION

These experiments in large groups of individuals indicate that quantitative rather than qualitative factors influence the specific antigenicity of influenza virus vaccines as tested in human beings. The chief and most significant differences in antibody response were encountered when different amounts of virus were injected. Inactivation of influenza virus, whether the result of formalinization, heating, or drying, caused but little alteration in the antigenicity of the preparations. Furthermore the addition of inert chick embryo protein, containing inactive virus, to a given vaccine did not significantly change its specific antigenicity. However, when infected chick embryo tissue was added to infected allantoic fluid and the virus in the mixture was not inactivated, a significantly more marked antibody response was obtained than with the allantoic fluid alone. It seems possible that this unexpected result may have been due to the presence in the embryo tissue of a greater quantity of virus than was indicated by the titration of its infectiousness for mice.

With both influenza A virus and influenza B virus evidence was obtained that the average antibody response of human beings is directly related, though not strictly proportional, to the amount of virus given. Although higher antibody levels resulted from the administration of relatively great quantities of virus in concentrated preparations (vaccine 57) than were encountered after the injection of unconcentrated vaccines, the data suggest that there are definite limits to antibody response since a further increase in the quantities of virus (vaccine 64) did not increase the response appreciably.

The present uncertain state of knowledge concerning the significance of circulating antibodies in resistance to infection by influenza viruses makes it hazardous to attempt any prediction as to the possible increased resistance which might follow the use of any of the vaccines tested in this study. It has been shown that antibody levels tend to be lower in acute phase sera obtained from cases of influenza than they are in the general population (18, 19). Furthermore it has been found that some reduction in the incidence of influenza A occurred in groups given a formalinized vaccine (6, 7, 20) which had increased the level of circulating antibodies. While these observations show that there is some relationship between specific circulating antibodies and resistance to clinical infection, there is also considerable evidence (18, 19) which indicates that individuals possessing the highest normal levels of circulating antibody are still susceptible to influenza.

None of the vaccines used in this study was capable of increasing the antibody level of all the individuals in a group to titers higher than those possessed by some of the members of the group before vaccination. Consequently the antibody level distribution curves before and after vaccination in each group overlapped by an appreciable extent (Fig. 2). Since the increased antibody titers which followed vaccination rapidly decreased with time, there is reason to think that whatever degree of increased resistance might result from the administration of a particular influenza vaccine would also become progressively less effective with the passage of time.

It should be reemphasized that the only satisfactory test of the possible efficacy of vaccines against influenza is extensive field trial under carefully controlled conditions. It seems probable that the better the antibody response following vaccination the more likely is the development of increased resistance. From the results of these studies it appears that concentrated virus suspensions produce greater antibody responses than do other kinds of vaccines.

#### SUMMARY

Eleven different preparations of influenza virus were used to vaccinate large groups of human beings. The antibody response to these vaccines was measured by means of the *in vitro* agglutination inhibition test, and the geometric mean titers of sera taken 2 weeks after vaccination were compared. From these comparisons the following conclusions were drawn:

1. There was a wide individual variation in the antibody response of human beings to the same preparation of influenza virus administered subcutaneously. The amount of antibody produced by a group with a low prevaccination antibody level was very nearly the same as the amount produced by groups that had higher initial levels.

2. The use of the X strain of distemper virus in the preparation of an influenza vaccine did not enhance the antigenicity of the influenza virus present.

3. Within certain limits the mean antibody response of human beings increased as the amount of virus injected was increased. When large amounts of influenza A virus were given, the antibody response was of the same order of magnitude as that which occurred following actual infection by this virus.

4. When the vaccine was prepared from allantoic fluid, there was no significant difference in the antibody response of human beings given active virus, formalin-inactivated virus, heat-inactivated virus, or virus inactivated by the drying process.

5. Ground infected chick embryos, when diluted with infected allantoic fluid, gave a greater antibody response than allantoic fluid alone (when the virus remained active). The antigenicity of such a preparation was diminished when the virus was inactivated by formalin.

6. Antibody levels 6 and 9 weeks after vaccination showed a marked drop

from the 2 week postvaccination levels. In a small group the antibody levels at 5 months were still further reduced. Those individuals who possessed the higher titers tended to lose their antibodies faster than did those at a lower level.

## BIBLIOGRAPHY

- 1 Andrewes, C. H., and Smith, W., *Brit J Exp Path.*, 1937, 18, 43
- 2 Francis, T., Jr., and Magill, T. P., *J Exp Med*, 1937, 65, 251
- 3 Smith, W., Andrewes, C. H., and Stuart Harns, C. H., *Great Britain Med Research Council, Special Rep Series No 228*, 1938 Section 7
- 4 Taylor, R. M. and Dreguss, M., *Am J Hyg.*, Section B, 1940, 31, 31
- 5 Horsfall, F. L., Jr., Lennette, E. H., and Rickard, E. R., *J Exp Med*, 1941, 73, 335
- 6 Horsfall, F. L., Jr., Lennette, E. H., Rickard, E. R., and Hirst, G. K., *Pub Health Rep, U S P H S*, 1941, 56, 1863
- 7 Martin, W. P., and Eaton, M. D., *Proc. Soc. Exp Biol and Med.*, 1941, 47, 405
- 8 Hirst, G. K., *Science*, 1941, 94, 22
- 9 Hirst, G. K., *J Exp Med*, 1942, 75, 49
- 10 Burnet, F. M., *Australian J Exp Biol and Med Sc.*, 1940, 18, 353
- 11 Henle, W., and Chambers, L. A., *Proc. Soc. Exp Biol and Med*, 1941, 46, 713
- 12 Nigg, C., Wilson, D. E., and Crowley J. H., *Am J Hyg* Section B, 1941, 34, 138.
- 13 Francis, T., Jr., *Science*, 1934, 80, 457
- 14 Francis, T., Jr., *Science*, 1940, 92, 405
- 15 Smith, W., Andrewes, C. H., and Laidlaw, P. P., *Lancet* 1933, 2, 66
- 16 Horsfall, F. L., Jr., and Lennette, E. H., *J Exp Med* 1940, 72, 247
- 17 Bauer J. H., and Pickels, E. G., *J Exp Med.*, 1940, 71, 83
- 18 Rickard, E. R., Lennette, E. H., and Horsfall, F. L., Jr., *Pub Health Rep, U S P H S*, 1940, 55, 2146
- 19 Rickard, E. R., Horsfall, F. L., Jr., Hirst, G. K., and Lennette, E. H., *Pub Health Rep, U S P H S*, 1941, 56, 1819
- 20 Brown, J. W., Eaton, M. D., Melklejohn, G., Lagen, J. B., and Kerr, W. J., *J Clin. Inv* 1941, 20, 663





# ARTERIAL HYPERTENSION IN RATS

## I. METHODS

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The blood pressure of anesthetized rats has been measured in the course of several experiments. Attempts were made to produce arterial hypertension<sup>1</sup> by a number of methods. These investigations were undertaken in order (1) to learn what the normal blood pressure of rats is under anesthesia, (2) to develop methods to bring about arterial hypertension, (3) to study some of the pathological changes in animals when chronic arterial hypertension has persisted, and (4) to provide preparations for ascertaining the action of pressor and depressor substances.

### *Methods*

Three hundred and fifty adult Norwegian white rats were used. Most were males. Blood pressures were measured with Hamilton's optical manometer, 5 per cent sodium citrate being used as an anticoagulant. All animals were anesthetized by intraperitoneal injection of pentobarbital sodium (4.5 mg per 100 gm. body weight). The right femoral artery was exposed, and a strong solution of novocaine applied to it to prevent contraction. A curved 23 gauge needle connected to the manometer was inserted into the artery through a small incision. Heparin was injected intravenously when continuous tracings were to be taken. Operations on the kidneys were performed under ether anesthesia, as the use of pentobarbital sodium resulted in many deaths owing to strangulation from obstruction of the upper respiratory passages.

The disadvantages of this method for measuring blood pressure are (1) animals are anesthetized and are, therefore, not under normal conditions, (2) only two or possibly three measurements can be made at different times on each animal, and (3) the rate of mortality from anesthesia alone is high (roughly 20 per cent). There are, however, several advantages: continuous records of the blood pressure can be made for as long as 2 hours, the blood pressure is probably at basal levels, and both systolic and diastolic pressures are measured with a considerable degree of accuracy.

<sup>1</sup> The term arterial hypertension, in this study, is intended to mean a vascular disease of rats, of which one manifestation is elevation of blood pressure.



to the criteria just provided was present in seven "normal" animals, two of these exhibited elevation of the diastolic pressures to more than 110 mm. Hg,

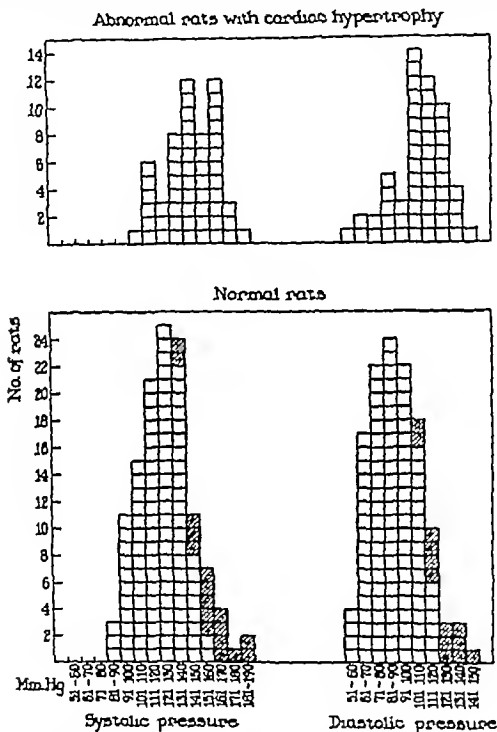


FIG. 1 Histograms of the blood pressures of 124 "normal" and 54 abnormal rats. The cross-hatched areas in the normal systolic histogram represent animals exhibiting diastolic pressures greater than 110 mm. Hg, those in the diastolic represent animals with systolic pressures greater than 150 mm. Hg. In every case the pulse pressure was greater than 24 mm. Hg. The abnormal rats all exhibited cardiac hypertrophy

and four to more than 100 mm. On the other hand the diastolic pressures of six were more than 110 mm, four of these being larger animals (350 to 500 gm.)

Since the presence of arterial hypertension is probably dependent upon the level of the diastolic pressure more than on the systolic, an attempt was made

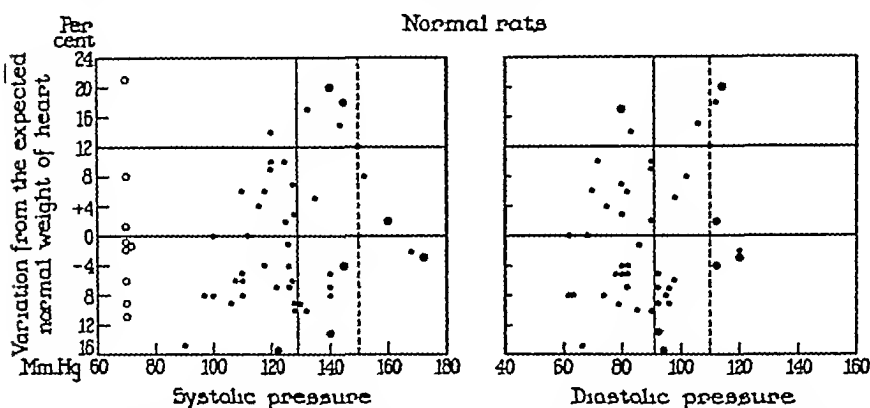


FIG 2 The blood pressures and variations in the weights of the hearts of 50 normal rats. The large dots represent the findings in animals weighing more than 400 gm. The circles in a vertical line near the left hand margin represent the hearts of those animals found to be in a state of shock when blood pressure was measured. The solid vertical lines represent the means of the pressures, the dotted lines arbitrary limits of "normal." It will be seen that most of the diastolic pressures of normal animals were below 100 mm Hg.

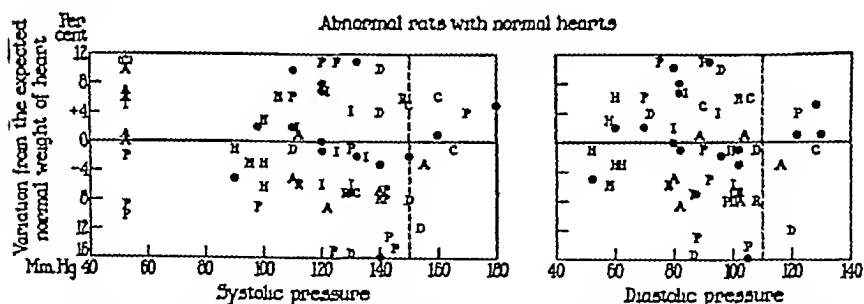


FIG 3 The blood pressures and variations in the weights of the hearts of abnormal rats having no cardiac hypertrophy. H = total occlusion of one ureter, I = injury by trauma, C = cellophane perinephritis, R = rayon sac applied to kidney, P = animals injected with pitressin and estradiol, A = animals injected with adrenalin in oil, D = animals injected with dihydroxyphenylalanine, ● = partial constriction of one renal artery. Other designations are the same as in Fig 2. There is no obvious relation between the level of the blood pressure and the size of the heart.

to ascertain in this series the upper limit of the normal diastolic pressure. When larger animals were excluded, as well as those with cardiac hypertrophy,

the diastolic pressure of all but one of the remainder lay below 110 mm Hg and of one other animal between 100 and 110. When these results are compared with those obtained in animals subjected to procedures designed to produce arterial hypertension (see below), many of which exhibited diastolic pressures greater than 100 or 110 mm. Hg, it will be seen that it is safe to regard 110 mm. Hg as the upper limit of "normal" (Fig 1). In the same animals the upper limit of the "normal" systolic pressure was somewhere between 140 and 150 mm, the more extreme variations make it desirable to regard 150 as the upper limit.

As the level of the blood pressure is easily influenced by experimental procedures (anesthesia) at the time of measurement, the size of the heart appears to be a more reliable index of the presence of chronic hypertension (Fig 3). In this study rats exhibiting cardiac hypertrophy<sup>3</sup> alone will, therefore, be considered to be "probably hypertensive," rats exhibiting cardiac hypertrophy and elevation of the diastolic pressure to a level greater than 110 mm. Hg to be "certainly hypertensive." Those animals with diastolic pressures greater than 110 mm Hg without cardiac hypertrophy will be considered to exhibit elevation of the blood pressure due to certain experimental conditions, and not to chronic arterial hypertension.<sup>4</sup>

### *The Production of Arterial Hypertension by Renal Injury*

#### *(a) Partial Constriction of One Renal Artery —*

Seventy two rats were anesthetized and the left kidney found through a mid abdominal incision. By retracting the kidney to the right of the midline, the origin of the renal artery was brought into view where it left the aorta. By careful dissection it was freed from the vein. A wire, 0.46 to 0.52 mm. in diameter, was placed along the artery and a ligature tied tightly around both the artery and the wire (1). When the wire was removed the artery was left partially constricted. Care was taken to see that the kidney was not completely anemic. In 14 instances the opposite kidney was removed (Fig. 4). Nine died after operation. The hearts of 56 were weighed.

Cardiac hypertrophy occurred in 39 of 56 animals. Blood pressure was elevated in 12. In 13 the affected kidney was completely infarcted. There

<sup>3</sup> Although cardiac hypertrophy was believed to exist when the weight of the ventricles was more than 12 per cent of that expected, this value is probably a little high for this series. The arithmetical mean variation in ventricular weight from the calculated mean was -0.4 per cent, when those animals with cardiac hypertrophy were excluded, the mean variation (43 rats) was -3.1 per cent. The standard deviation of fifty rats was  $\pm 9.0 \pm 0.6$  per cent, the mean  $0 \pm 0.9$  per cent.

<sup>4</sup> "Arterial hypertension" when used in this report means, therefore, (1) diastolic pressure of 111 mm. Hg or more, and (2) enlargement of the heart 12 per cent or more than that expected.

was no difference in the degree of hypertrophy after (a) constriction of one renal artery and (b) constriction plus nephrectomy of the opposite kidney, although the result in (b) was more constant (Table I)

When animals with an intact kidney were allowed to survive for 8 weeks or more, a few (5 of 15) lost weight and died. Elevation of urea nitrogen in the blood was found in 2, and there were vascular lesions in some of the organs,

#### Constriction of renal artery

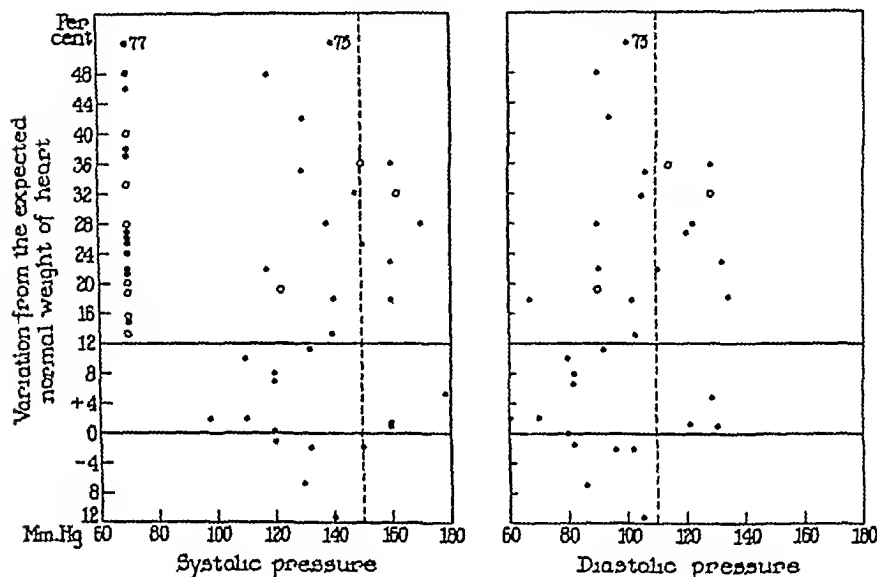


FIG 4 The blood pressures and variations in the weights of the hearts of rats with partial constriction of one renal artery ● = opposite kidney intact, ○ = nephrectomy of opposite kidney. The vertical line of dots near the left hand margin represents animals in a state of shock when blood pressure was measured and those dying without a measurement being made

including the kidneys. One animal died after delivery of a litter. There was no evidence that hypertension, once established, was transient (Fig 8)

#### (b) Unilateral Hydronephrosis —

The left ureter of fifteen rats was cut close to the bladder and brought through the skin of the flank. In six the ureter was occluded, in nine the kidney continued to function and to discharge urine through the side of the animal (2). The wounds healed well.

In those cases (nine) in which the kidneys continued to function, hydronephrosis of mild degree developed, there was cardiac hypertrophy in all and

TABLE I  
Summary of Results

Procedure	Total No. rats	Deaths* within 24 hrs.	Deaths after 24 hrs.	Hearts weighed	Hearts enlarged	Deviation, significant, from normal	Blood pressures measured	Shock†	Diastolic pressure‡			Cardiac hypertrophy and diastolic pressure > 110	Loss of 10 per cent body weight**
									< 101 mm. Hg	> 100 mm. Hg	> 110 mm. Hg		
Normal	163	—	—	50	7	—	163	39	90	34	15	3	—
Per cent					14					27	12	6	
Constriction of one renal artery	57	5	4	46	29	Yes	45	11	15	19	12	6	12
Per cent					63					58	35	19	
Constriction of one renal artery and opposite nephrectomy	15	4	7	10	10	Yes	4	0	1	3	2	2	2
Per cent					100					75	50	50	
Hydronephrosis with function	10	1	0	9	9	Yes	9	0	0	9	7	7	0
Per cent					100					100	78	78	
Occlusion of ureter	6	2	0	6	0	—	6	0	6	0	0	0	0
Per cent					0					0	0	0	
Traumatic injury	21	5	2	14	6	Yes	14	2	7	7	3	3	0
Per cent					45					88	25	100	
Cellophane perinephritis	22	0	0	22	16	Yes	22	5	4	13	5	4	0
Per cent					73					77	29	24	
Rayon sac about kidney	4	0	0	4	0	—	4	0	1	3	0	0	0
Per cent					0					75	0	0	
Left kidney totally destroyed.	20	—	2	20	13	Yes	17	5	7	5	2	2	—
Per cent					65					42	17	17	
Injection of adrenalin	18	8	1	18	7	Yes	8	0	3	5	3	1	0
Per cent					39					63	38	13	
Injection of pitressin and sex hormone	20	1	0	19	4	No	17	3	9	5	3	1	0
Per cent					21					38	21	8	
Injection of dihydroxy phenylalanine	12	0	0	12	2	No	12	0	3	9	7	2	1
Per cent					17					75	58	17	

\* = spontaneous. † = by comparison of means. ‡ = pulse pressure < 25 mm. Hg systolic pressure > 88 mm. § = excluding those in shock. \*\* = one week or more after procedure.

arterial hypertension in seven. In those (six) with total occlusion of the ureter there were large hydronephrotic sacs and no hypertension (Fig 5)

### (c) Unilateral Renal Trauma —

The left kidneys of 21 anesthetized rats were isolated in a fold of skin in the flanks and injured with light strokes of a hammer. Five animals died from rupture of the kidney and hemorrhage.

Cardiac hypertrophy resulted in six of fourteen, the mean variation being significantly greater than the normal.<sup>7</sup> It lasted 4 months in three cases.

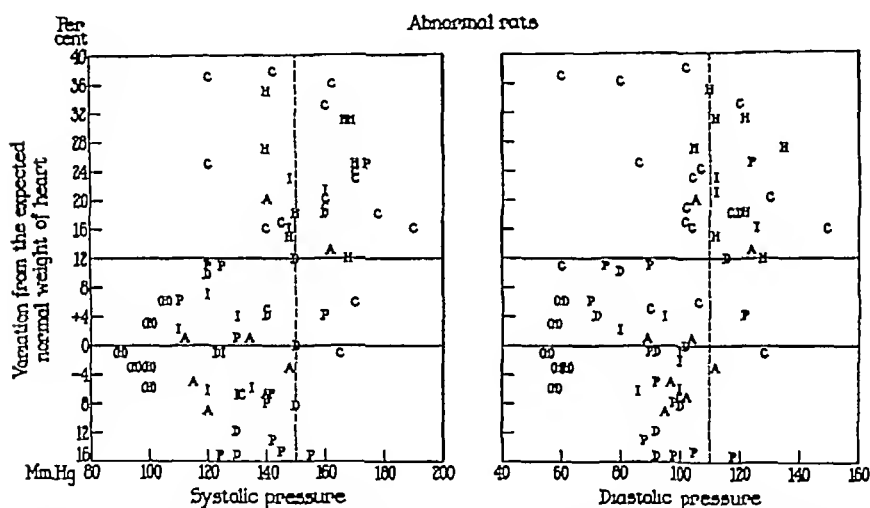


FIG 5 The blood pressures and variations in the weights of the hearts of all abnormal rats except those in Fig 4. Notations same as Fig 3, except that H = hydronephrosis with functioning kidney, (H) = total occlusion of ureter.

(Fig 8) which exhibited arterial hypertension (Fig 5). The left kidneys of the six with cardiac hypertrophy were scarred and contracted with small healed infarcts in the cortices.

### (d) Perinephritis —

The left kidneys of 22 anesthetized rats were covered with a sac of cellophane loosely tied about the renal pedicle (4). In four others a rayon sac was used instead.

<sup>7</sup> The results (changes in the weight of the hearts) were examined statistically by a method found in Pearl ((3), p 343). The mean of the variation of heart weight from that expected was  $+10.3 \pm 1.1$  per cent. In comparison with the mean of the series of normal rats this change was significant.



Cardiac hypertrophy developed in sixteen rats, and arterial hypertension in four (Fig 5). Infection in the sac was present in nine, of which six showed cardiac hypertrophy. Measurements indicated that the systolic pressure tended to be elevated more than the diastolic, especially during the first 30

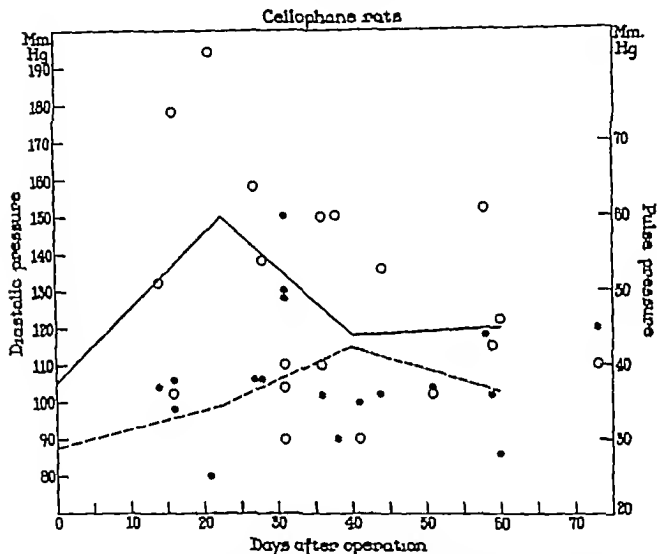


FIG. 6. The pulse pressures (O) and the diastolic pressures (●) of rats with cellophane perinephritis. The average pulse pressures (solid line), and the average diastolic pressures (dotted line), do not represent significant changes by Fisher's method for the analysis of small samples (7) as there were not enough observations. There appears, however, to be a definite tendency for the pulse pressure to be increased during the first 30 days.

days after operation (Fig 6). When rayon was used there was no enlargement of the heart.

(e) *Rats with Destruction of One Kidney*—In 20 instances among those previously cited the left kidneys were either totally infarcted by the procedure or completely destroyed by infection. Infarction occurred thirteen times on constriction of the left renal artery, and once after the kidney had been injured,

cardiac hypertrophy was observed 7 to 129 days later in ten. In two infection destroyed the kidney, the heart of one was enlarged. The weights of the hearts of two the kidneys of which were destroyed by infection in the cellophane sac were within normal limits. Two died of renal insufficiency 3 days after infarction of their left kidneys and removal of the right ones, their hearts were

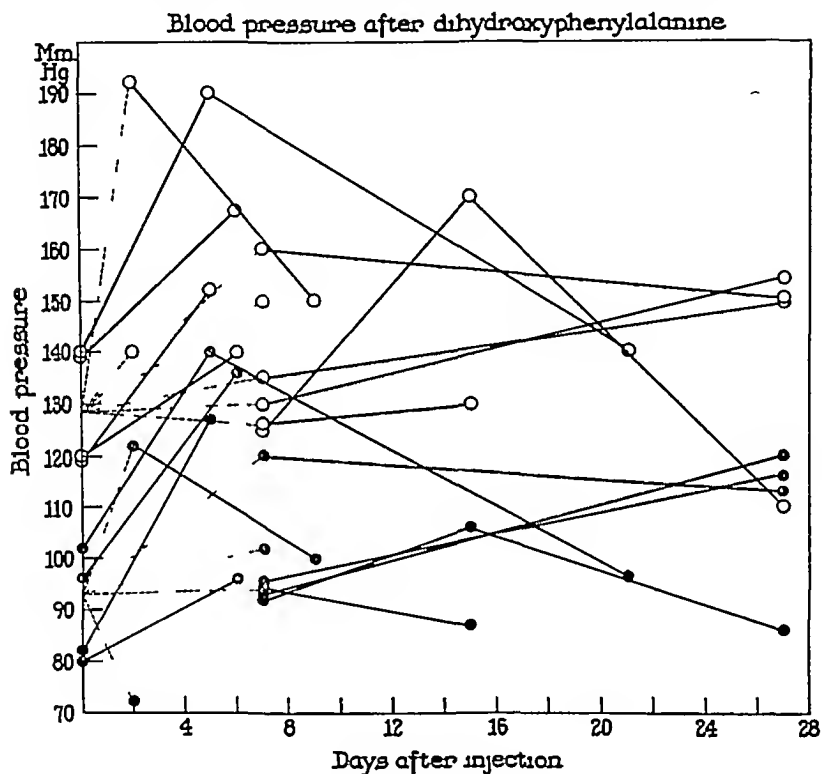


FIG 7 The blood pressure of 12 rats injected with dihydroxyphenylalanine. There is a tendency for it to become elevated for a time, although this change is not significant according to Fisher's method for the analysis of small samples (7). The solid lines connect different measurements on the same rat, the dotted lines have their origin in points representing mean normal values. ○ = systolic pressure, ● = diastolic pressure.

enlarged. The mean variation from normal of the weights of the hearts was significantly increased.

#### *Attempts to Produce Arterial Hypertension by Chemical Methods*

##### *(a) Pitressin and Female Sex Hormone —*

Seven female and thirteen male rats were given by intramuscular injection  $\alpha$ -estradiol (1500 to 2000 rat units) in divided doses during 10 days, and then given

pitressin (6 to 8 units per 100 gm body weight) The procedure of Byrom (5) was followed except that adult rats were used Blood pressures were measured up to 70 days later

Cardiac hypertrophy occurred in four animals but the statistical change for the series was not significant. The diastolic pressure was elevated in three on more than one occasion, one of which could be said to exhibit arterial hypertension (Fig 5) All but two rats weighed less than 325 gm

(b) *Adrenalin* —

A single dose of adrenalin in oil, 10 mg was injected intramuscularly into each of eighteen rats. Eight died within 24 hours. The remainder were observed up to 20 days.

Cardiac hypertrophy occurred in seven and the mean enlargement for the whole series was significant.\* Diastolic pressures became elevated in three (Fig 5) Only one could be said to have developed arterial hypertension. Cardiac hypertrophy was present in four of the eight dying soon after the procedure, and many hemorrhages were seen in the kidneys.

(c) *Dihydroxyphenylalanine* —

The intravenous injection of dihydroxyphenylalanine resulted in an immediate and prolonged pressor response, the curves obtained resembling those produced by renin. In each of ten rats, the injection of 3 to 10 mg of this amino acid was followed by a rise in the level of diastolic blood pressure from 20 to 60 mm. Hg the height of the reaction occurring 2 to 7 minutes after injection. It continued to be elevated from 12 to 40 minutes. Injection of tyrosine did not occasion this response. Six rats, therefore, were given 20 mg of this substance intraperitoneally, and six, 10 mg. intravenously. Blood pressures were measured up to 27 days.

Cardiac hypertrophy occurred only in two, not a significant change for the series (Fig 5) In nine, however, the blood pressure rose (Fig 7) Two of the remainder were in a state of shock when measurements were made

#### DISCUSSION

It is probable that the standards adopted as representing the range of blood pressure of normal rats anesthetized with pentobarbital sodium are somewhat rigid. The extreme variability of blood pressure and the possibility that arterial hypertension may be present in "normal" animals makes it necessary, however, that the upper limits be high. The presence of cardiac hypertrophy

\* The mean change for the whole series was  $+8.3 \pm 1.7$  per cent. The standard deviation was  $10.9 \pm 1.2$  per cent. When this mean was compared with that of the normal series, it was found that the change was a significant one. The coefficient of variation of this series, as with the others, was naturally large.

is probably a better index of hypertension (1). The fact that normal rats may exhibit cardiac hypertrophy, elevation of blood pressure, or both, and that abnormal rats may have cardiac hypertrophy with or without elevation of blood pressure makes the whole matter confusing. It is likely that hypertrophy of the ventricles is associated with chronic arterial hypertension whatever the level of the blood pressure may be under anesthesia<sup>9</sup>—it is almost certain that rats with hypertrophied hearts and elevated blood pressures under anesthesia are hypertensive.

When the different procedures here discussed are reviewed, it is seen that rats, or at least some of them, are susceptible to arterial hypertension. Of four operative methods involving unilateral renal injury, all resulted in cardiac hypertrophy of significant degree. The heart was large even when the affected kidney was functionless and totally infarcted, as in the case of rats subjected to the Goldblatt technique. The persistence of its enlargement was not dependent upon ischemic and functioning renal tissue.

There is little doubt that injury to one kidney is often followed by persistent chronic arterial hypertension (Fig. 8). This condition is usually associated with vascular lesions in the opposite kidney (6). In those cases where the affected one is destroyed by infarction or infection, arterial hypertension probably persists because of the presence of vascular disease in the other, secondary to the initial renal damage.

Attempts were made at producing hypertension by chemical methods in the hope that these substances might set in motion an irreversible process which would lead to chronic arterial hypertension. The method failed in those animals injected with pitressin, for only one was definitely hypertensive 10 weeks later though four exhibited cardiac enlargement in 7 days. When adrenalin was injected cardiac hypertrophy occurred to a significant degree, but in no case did it persist more than 14 days after injection, and in only two cases more than 3. The injection of dihydroxyphenylalanine (9) resulted in cardiac hypertrophy only twice, these animals were considered to be "certainly hypertensive." Although rats frequently exhibit hypertension after one kidney is damaged, single injections of these pressor substances brought about little prolonged effect.

An interesting observation is the rapidity with which cardiac hypertrophy occurred. The injection of large doses of adrenalin, of pitressin (in three cases) and of injury to a single kidney after partial constriction of a renal artery, often resulted in enlargement of the ventricles in 1 to 3 days. The increase in weight was not due to the presence of edema, the hearts felt firm, the left ventricles were thick, and there was no evidence of general edema in the weight of the animals.

<sup>9</sup> Wilson and Byrom (8) found that the blood pressure of rats exhibiting "malignant" hypertension was extremely variable.

# Abnormal rats

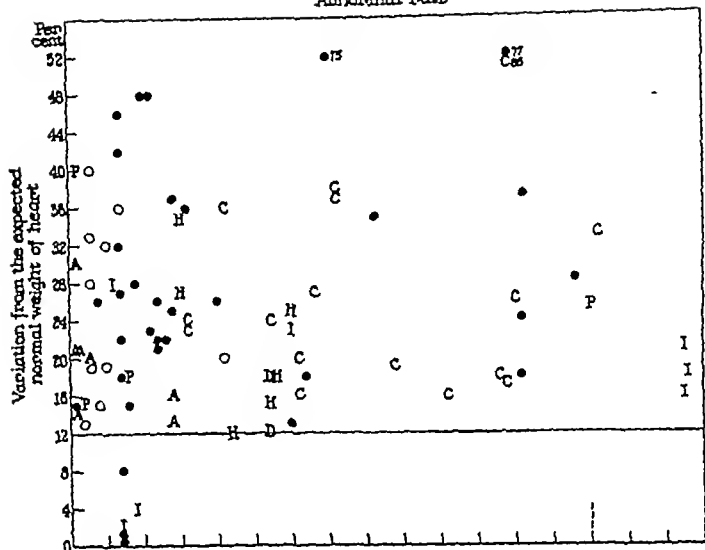


Fig 8a

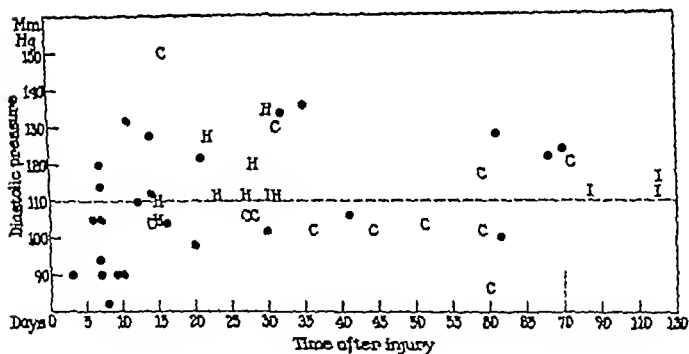


Fig 8b

Fig 8. The relation of the production and persistence of hypertension to the number of days after renal injury. Notations same as in Figs. 3, 4, and 5. (a) Variations in the weights of the hearts. The hearts of many animals became enlarged very soon after the procedures designed to produce arterial hypertension. (b) The diastolic blood pressure of rats with cardiac hypertrophy. There is no obvious tendency for the blood pressure to become lower. (a) includes all rats exhibiting enlarged hearts and also those killed within 10 days after injury.

It is obvious, therefore, that rats are susceptible to arterial hypertension, even when only one kidney is injured. The relation of this condition to disease in the blood vessels of the opposite kidney will be discussed in a subsequent communication (6).

#### SUMMARY

Normal standards for the blood pressure of rats under pentobarbital sodium anesthesia have been ascertained. Arterial hypertension did not consistently follow the injection of estradiol and pitressin in adult rats, and only transient hypertension occurred after the injection of dihydroxyphenylalanine. The injection of adrenalin in oil, however, was followed by cardiac hypertrophy, and it also resulted from (a) partial constriction of one renal artery, (b) the production of unilateral hydronephrosis, (c) traumatic injury to one kidney, (d) inducing unilateral perinephritis with a cellophane membrane. The blood pressure in many of the animals became elevated.

In rats the weight of the heart is probably a more reliable index of the presence of the hypertensive state than is one measurement, or two, of blood pressure under anesthesia. The latter is extremely variable, both in normal and in hypertensive animals. Rats are, however, liable to hypertension under natural circumstances, and it can be easily induced in a number of ways. The weight of the heart may then become rapidly increased. To judge from the findings in this species, rats are very susceptible to the production of the hypertensive state, in comparison with other animals.

The author is indebted to Dr J. Murray Steele who developed this technique for measuring blood pressure of rats, and who kindly made available for use in this study the measurements of blood pressure of 39 normal animals.

#### BIBLIOGRAPHY

- 1 Rytand, D. A., *J. Clin. Inv.*, 1938, **17**, 391
- 2 Schroeder, H. A., and Adams, M. H., *J. Exp. Med.*, 1940, **73**, 531
- 3 Pearl, R., Introduction to medical biometry and statistics, 3rd edition, Philadelphia, W. B. Saunders Co., 1940
- 4 Page, I. H., *Science*, 1939, **89**, 273
- 5 Byrom, F. B., *Lancet*, 1938, **1**, 129
- 6 Schroeder, H. A., and Neumann, C., *J. Exp. Med.*, 1942, **75**, 527
- 7 Fischer, R. A., Statistical methods for research workers, 5th edition, London, Oliver and Boyd, 1934
- 8 Wilson, C., and Byrom, F. B., *Lancet*, 1939, **1**, 136
- 9 Bing, R. A., *Am. J. Physiol.*, 1941, **132**, 497

# ARTERIAL HYPERTENSION IN RATS

## II. EFFECTS ON THE KIDNEYS

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PLATES 13 TO 16

(Received for publication, February 9, 1942)

The exact relation between disease of the renal arterioles and arterial hypertension is not understood. It is not known whether the observed sclerosis and necrosis of the arterioles of the kidneys cause renal ischemia and therefore hypertension or are merely a consequence of elevation of the blood pressure. In some animals the evidence gained in experiments suggests, however, that the appearance in the renal arterioles results from hypertension. By partially constricting one renal artery in rats Wilson and Byrom (1) were able to bring about elevation of blood pressure and necrotizing arteriolitis in the vessels of the other kidney, indicating that in rats, at least, arteriolar disease is occasioned by hypertension. Their work has not received the notice it deserves. If their findings were substantiated in other animals and in man, some of the factors contributing to arterial hypertension would be made more clear. Unfortunately the experiment cannot be performed in dogs, as chronic hypertension does not usually result from affecting one kidney when the other is intact.

It appeared rewarding, on the plan of Wilson and Byrom, to attempt to ascertain further the relation of arteriolar disease to arterial hypertension in rats and to observe the effects upon one kidney of various kinds of injury to the other. It has been shown that unilateral renal injury results in cardiac hypertrophy, an indication of the presence of hypertension (2). The current study deals with changes in the renal arterioles associated with the latter condition.

### *Methods*

The left kidneys of 80 rats were injured either by partial constriction of the renal artery, by the production of hydronephrosis, by trauma, or by placing cellophane around them (2). Eighteen more rats were injected with adrenalin in oil or pitressin and estradiol, and six with other substances (renin, dihydroxyphenylalanine, tyrosinase).

The animals were killed, after a suitable interval, the hearts weighed as previously described (2), and the kidneys fixed in Zenker acetic acid solution. Sections were stained either with eosin methylene blue hematoxylin and eosin, or Mallory's connective tissue stain. They were then examined by one of us who had had no previous knowledge of which of the rats had exhibited arterial hypertension. The degree of the following anatomical changes in each kidney was estimated and recorded in terms

of one to four plus the presence of hyalinization of the glomeruli singly or in groups, proliferation of the parietal layer of Bowman's capsule (crescent formation), infiltration of the interstitial tissue by round cells, atrophy of the tubules, and replacement fibrosis. The condition of the vessels was estimated in a similar manner by ascertaining the presence or absence of the following: intimal proliferation of the arterioles, necrosis of their walls, hypertrophy of their muscles, hyaline degeneration, hyperplasia of the internal elastic membrane of the small arteries, and hyalinization of their walls. The presence of small hemorrhages in the substance of the kidney was noted, as was any other abnormality. A decision was then made as to the resemblance of these kidneys to those found in arterial hypertension particularly in so far as vascular change was concerned. The results of the microscopic examination were then compared with data obtained during the life of the animals, and with such changes as had taken place in the weights of their hearts.

### RESULTS

The pathological findings were used to group the rats into two general classes. In the one, arteriolar lesions, including marked hypertrophy of the muscle, narrowing of the lumen, and partial to almost complete necrosis of the wall were the predominating features. These lesions bore a close resemblance to the arteriolar changes in the kidneys of rapidly progressive hypertension in human beings. In the other, arteriolar lesions were either non-existent or limited to variable but slight hypertrophy of the muscle. In this group the predominating pathological features were confined to the glomeruli, which showed thickening of the parietal layer of Bowman's capsule and various stages of hyalinization. Only the kidneys exhibiting arteriolar changes were believed to represent those of hypertensive animals. How closely this division according to pathological findings alone corresponded with other signs of hypertension such as the level of the blood pressure and cardiac weight found post-mortem will now be described.

Fifty-nine rats exhibited cardiac hypertrophy. The kidneys of 51 (86 per cent) showed changes in the renal arterioles of various degrees and in 3 others slight lesions were noticed. In 45 cases there was no cardiac hypertrophy, in 36 there were few or no renal arteriolar lesions (Tables I to V).

When one kidney was injured by hydronephrosis, by partial constriction of the renal artery, by trauma, or by cellophane, arteriolar changes occurred in the opposite kidney with great regularity (Figs 1 to 13). Of 52 rats so treated which exhibited cardiac hypertrophy, renal arteriolar lesions occurred in 47. Cardiac hypertrophy did not occur in the cases of 25, yet in the unaffected kidneys of 9 of these similar lesions were seen in the arterioles (Tables I to IV).

Rats given various chemical compounds (in an attempt to induce hypertension) and exhibiting cardiac hypertrophy developed renal arteriolar lesions with less regularity (Table V). Of 2 injected with pitressin and estradiol benzoate, renal changes occurred in 1. Of 4 injected with adrenalin in oil,



**TABLE I**  
*Effects of Unilateral Hydronephrosis*

Rat No.	Change in heart weight: <small>per cent</small>	Blood pressure: <small>mm. Hg</small>	Time after injury <small>days</small>	Kidney examined	Anatomical changes in kidneys								Remarks	
					Arterioles			Change in arteries	Tubular atrophy	Glomerular hyalinization	Small hemorrhages	Interstitial tissue**		Kidney hypertrophy††
					Muscular hypertrophy	Hyaline degeneration	Necrosis of wall							
H 96	+35	140/110	15	Both	++	+			+	+			Yes	Slight hydronephrosis
H 99	+31	167/112	23	R	++	+			+	+			Yes	Slight hydronephrosis
H 150	+31	148/112	23	L R	++ ++				++	+++		F	Yes	Moderate hydronephrosis
H 95	+27	140/103	15	Both	++	+			+	+			Yes	Slight hydronephrosis
H 97	+25	170/135	20	Both	++	+			+	++			Yes	Slight hydronephrosis
H 94	+18	150/120	28	Both	++	+			+	++			Yes	Slight hydronephrosis
H 100	+15	148/117	27	L R	++ ++	+		++ +	+++ ++	++ +	+	F F	Yes	Slight hydronephrosis
H 148	+14	168/122	109	L R	++ ++	++ ++	++ +++		++++ +	++++ +++		F and R	Yes	Destruction of kidney
H 93	+12	166/128	22	Both	++	+			+	++			Yes	Slight hydronephrosis
H 149§§	+6	105/60	33	L R	 +		++++	++++	++ +	++ +		F and R	No	Destruction of kidney
H 147§§	+3	100/58	33	L R	 +	++++	++++	++++ +	++++ +	++++ +		F and R	No	Destruction of kidney
H 143§§	-1	90/52	42	L R					++	+++ +			No	Marked hydronephrosis
H 141§§	-3	93/60	42	L R					++	+++ +		F	No	Marked hydronephrosis
H 145§§	-3	100/62	33	L R					+++ +	++ +		F	No	Destruction of kidney
H 146§§	-6	100/58	33	L R					++	+++ ±			No	Marked hydronephrosis

§§ Total ureteral occlusion.

In the tables the significance of the symbols is as follows

= based on the formulas of Rydand (5)

† = measured by Hamilton's optical manometer The first figure represents the systolic, the second the diastolic pressure.

‡ = i.e. proliferation of internal elastic membrane, hyalinization of walls, muscular hypertrophy

§ = i.e. singly or in large foci.

\*\* = F indicates fibrosis, R indicates infiltration by round cells.

†† = an estimation of the general appearance of the kidney and its resemblance to those observed in hypertensive animals.

Changes are indicated by a plus (+) sign, and their degree estimated on the basis of one to four plus. When no symbol is given, there were no lesions.

they were present in 2 The kidneys were essentially normal in 10 of 12 animals failing to develop cardiac enlargement

TABLE II  
*Effects of Unilateral Trauma*

Rat No	Change in heart weight*	Blood pressure†	Time after injury	Kidney examined	Anatomical changes in kidneys								Remarks	
					Arterioles			Change in arteries‡	Tubular atrophy	Glomerular hyalinization¶	Small hemorrhages	Interstitial tissue**		Kidney hypertensivett
					Muscular hypertrophy	Hyaline degeneration	Necrosis of wall							
	per cent	mm Hg	days											
I 21	+31		24	L R	± ±	± ±							No	Hemorrhages
I 19	+23	148/112	30	L R	± ±				+ +	+ +			No	No gross lesions
I 9	+21	160/112	120	L R	+++ +++	+++ +++			+ +	± ±		F and R	Yes	
I 10	+18	95/72	122	L R	+ +	+ +		+ +	+ +++	+ +		F	Yes	
I 20	+7	120/84	24	L R	± ±				+++ +++	++++ ±		F and R	No	Split and scarred
I 11	+5		122	L R					+ +	+ +			No	
I 2	+4	130/95	9	L R					+ +	+ +			No	Grossly scarred
I 5	+2	100/80	7	L R	+ +	+			++ ++	++ ++		F	No	Necrotic and infarcted
I 4	-1	125/100	35	L R					+ +	+ +			No	Contracted and scarred
I 17	-2	135/100	84	L R					+ +	+ +		F and R	No	Scarred

Two were given dihydroxyphenylalanine, 1 renin, 3 tyrosinase The arterioles of their kidneys were unchanged No lesions were found in the kidneys of 10 normal rats

There was a very rough correlation between degrees of cardiac hypertrophy and changes in the renal arterioles induced by the several varieties of unilateral renal injury The most marked renal lesions were in general associated with the greatest cardiac hypertrophy, but there were many exceptions An at-

tempt was made to find whether there was a relation between the degree of renal damage in the untreated kidney and the number of days after the other was injured. Marked changes occurred as early as 7 to 14 days. Five animals developing "malignant hypertension" (1) were allowed to survive for 2 months or more and their kidneys were more severely damaged.

When elevation of the blood pressure was considered an indication of the hypertensive state, about the same relative number of animals (88 per cent) developed changes in their kidneys as when cardiac hypertrophy was taken as the sign (Table VI). Single estimations of blood pressure have little value, especially when the pressure is normal or low in the presence of cardiac hypertrophy, since a state of shock is easily induced when such a condition obtains. But of the 32 animals which exhibited elevation of blood pressure 28 developed renal vascular lesions, and in 12 these included necrosis. Of 8 rats with normal hearts and elevated blood pressures, they were present in 6. When cardiac hypertrophy and elevation of blood pressure were considered together, roughly the same proportion (85 per cent) exhibited renal lesions and a similar one, necrosis of arterioles. Renal lesions were found in only 5 animals with normal hearts and normal blood pressures—all in rats subjected to partial constriction of a renal artery (Table VI).

The survival of renal tissue in the injured kidney at death was not always necessary for the development of hypertension or vascular lesions. The affected kidney was atrophic in 13 animals in which the renal artery had been constricted, 7 of these developed cardiac hypertrophy and 9 arteriolar lesions. On the other hand functioning of a partially injured hydronephrotic kidney seemed to be necessary for the development of hypertension and arteriolar lesions (Table I, Figs. 1 to 7).

Cardiac hypertrophy occurred in 3 cases when the left kidneys had been injured and the right ones remained normal. In 1 rat the injured organ was completely atrophied, in 1 full of hemorrhagic areas, and in the other the renal tubules were atrophied. In 2 cases after adrenalin, and 1 after pitressin and estradiol had been given, cardiac hypertrophy was found in the presence of normal kidneys.

Renal arteriolar lesions occurred without cardiac hypertrophy in 11 animals. The blood pressure was elevated in all but 5 in which renal arteries were constricted. It was elevated without cardiac hypertrophy in only 2 instances when the kidney was considered normal.

Although in most instances glomeruli showed hyaline degeneration, in only 3 was there seen proliferation of the parietal layer of Bowman's capsule (crescent formation), such as occurs in glomerulonephritis. On the other hand, necrosis of the walls of arterioles was common, being found in 34 animals. Five of these did not exhibit cardiac hypertrophy although the blood pressures of 3 were elevated.

Change in heart weight*	Blood pressure†	Time after injury	Kidney examined	Anatomical changes in kidneys									Remarks
				Arterioles			Change in arteries‡	Tubular atrophy	Glomerular hyalinization§	Small hemorrhages	Interstitial tissue**	Kidney hypertensive††	
				Muscular hypertrophy	Hyaline degeneration	Necrosis of wall							
per cent	mm.Hg	days											
+77		59	L R	+ +	++++ ++++	++ ++++	+ +	++++ ++++	+++ ++		F F	Yes	Partially atrophic
+75	168/135	35	L R	+ ++	++ +	+++ ++++	++ +++	+++ ++	+++ ++		F F	Yes	
+52	110/80	35	L R	++ ++++	++ ++++	++ ++++	+ ++	++++ ++++	++++ ++		F F	Yes	
+48	118/90	10	L R	++ ++++	+ +	+ +		+++	+++	+ +	F and R R	Yes	
+48		11	L R	+++ ++++	++ +	+ +	++ ++	+++ ++++	++ +	+ +	F F	Yes	
+46	88/58	7	Both	+	++	+	+	+	+	+	F and R	Yes	
+37	80/49	14	L R	 +	 ++	 ++	 	++++ +	+++ +	++++	F	Yes	Partially atrophic Enlarged
+37	40/22	61	L R	+++ ++++	+ ++++	++++ ++++	+ ++	++++ ++++	+++ ++	 +	F and R F	Yes	
+36	120/104	16	L R	++ 	+ 	+ 			+	+		Yes	Completely atrophic
+35	130/106	41	L R	++ 	+ 							Yes	Completely atrophic
+32	148/105	7	L R	++ ++	++ +		++ ++	+ ++	+ +		F	Yes	
+28	170/122	68	L R	+ 	+++ 	++ 	++ 		+	+		Yes	Completely atrophic
+28	138/90	9	L R	+ ++	+ +	+ 		+ ++	+ ++	+		Yes	
+27	146/120	7	Both	+++	+	++		+++	++	+	F and R	Yes	
+26	110/64	12	L R	++ ++	++ ++	+ +	+ ++	++ ++	++ +	+	F	Yes	
+26	72/62	4	L R						+			No	Completely atrophic
+26	110/98	20	L  R	  ++	  +	  	  +	  +	  +	  	  	  Yes	Almost completely fibrotic

TABLE III—*Continued*

Rat No.	Change in heart weight gms	Blood pressure mm Hg	Time after injury days	Kidney examined	Anatomical changes in kidneys									Remarks	
					Arterioles			Change in arterioles	Tubular atrophy	Glomerular hyalinization	Small hemorrhages	Interstitial thickening	Kidney hypertensivized		
					Muscular hypertrophy	Hyaline degeneration	Necrosis of wall								
122	+25	130/112	14	Both	++	+	+		+	+				Yes	
167	+24	50/28	61	L											Uremia. Completely atrophic
				R	+++	++	+++	++	+	+	+	F	Yes		
170	+18	140/100	61	L											Completely atrophic
				R	+					+			No		
104	+18	160/134	32	Both	++				++	+		F and R	Yes		
126	+13	112/80	8	L	+	+	+		++++	++++	+	F and R	Yes		
				R	++	+	+		++++	++++	+		Yes		
132	+13	140/102	30	L		++		+	+++	+++		F	Yes		
				R	+++	++	++	++	+	+			Yes		
176	+11	132/92	68	L										Atrophic	
				R	+++					+	+		Yes		
118	+4	120/82	12	L										Atrophic	
				R					++	+			No		
160	+5	178/128	61	L										Atrophic Enlarged	
				R									No		
172	+3	110/60	73	L										Atrophic	
				R	+++	+++	++	+	+	++			Yes		
162	+1	160/122	7	R	+++	+	+	+	+++	+		F	Yes		
161	+1	160/130	70	L										Atrophic	
				R	++	+++	+	++	++	++			Yes		
153	-1	120/82	35	L	+	+++	++	++	++++	++++		F	Yes		
				R	+++	++		++	+	+			Yes		
160	-2	250/202	7	R	+++					+			Yes		
166	-2	132/96	36	R	+++	++			++	+			Yes		
164	-5	88/42	56	L										Atrophic	
				R						±			No		
GN14055	+22	162/128	5	L	++	++				±			Yes		

§§ Opposite (right) nephrectomy performed.

One difficulty has been the lack of reliable indices to establish the presence of the hypertensive state. Attempts have been made (2) to learn the normal blood pressure of rats and so to ascertain the development of hypertension. To this end greater emphasis was placed upon the presence of cardiac hypertrophy than upon elevation of the blood pressure, since this was known to be easily influenced by environmental factors and by stages in the disease itself (1). If renal vascular disease is also an expression of arterial hypertension, it becomes obvious that there is no single reliable way of establishing the existence of the hypertensive state. One or more of the phenomena, in all combinations, cardiac hypertrophy, elevation of blood pressure, and renal vascular disease occurred in a small proportion of the animals. Perhaps the best index of the hypertensive state is the presence of two of these three.

#### SUMMARY AND CONCLUSIONS

1 When rats developed cardiac hypertrophy or elevation of blood pressure as a result of one of several methods designed to bring about arterial hypertension, renal vascular disease occurred frequently.

2 When injury to one kidney was followed by cardiac hypertrophy or elevation of blood pressure, vascular lesions were found with considerable regularity in the opposite one, as well as in the one injured.

3 Renal lesions rarely occurred in the absence of cardiac hypertrophy or elevated blood pressure.

4 Renal vascular lesions in rats are occasioned, therefore, by injury to one kidney and are usually associated with, and dependent on, the presence of arterial hypertension.

#### BIBLIOGRAPHY

- 1 Wilson, C, and Byrom, F B, *Lancet*, 1939, 1, 136
- 2 Schroeder, H A, *J Exp Med*, 1942, 75, 513
- 3 Winternitz, M C, Nylon, E, Waters, L L, and Katzenstein, R, *Yale J Biol and Med*, 1940, 12, 623
- 4 Friedman, B, Jarman, J, and Klemperer, P, *Am J Med Sc*, 1941, 202, 20
- 5 Ryland, D A, *J Clin Inv*, 1938, 17, 391

#### EXPLANATION OF PLATES

These photographs were made by Mr Joseph B Haulenbeek

#### PLATE 13

FIGS 1 to 6 Photographs of sections of the left kidneys of rats exhibiting hydro-nephrosis. Fig 1, normal kidney, Fig 2, rat H 94, Fig 3, rat H 97, Fig 4, rat H 100, Fig 5, rat H 150, Fig 6, rat H 147. The kidneys of all except that of No H 147 functioned. Arterial hypertension was exhibited by all animals except No H 147. Hematoxylin and eosin stain  $\times 2$ .

FIG 7 Photomicrograph of right kidney of rat H 96, of which the left was hydro-nephrotic. Arterial hypertension was present. The glomerular arteriole is diseased, its wall thickened. Hematoxylin and eosin stain  $\times 500$ .



#### PLATE 14

FIGS 8 and 9 Fig 8, photomicrograph of section of right kidney, and Fig 9, of left kidney of rat G 158 The left renal artery had been partially constricted 35 days previously, and the rat exhibited arterial hypertension Vascular changes, hyaline degeneration, hypertrophy of muscle, and necrosis are present in the arterioles of both sections to a similar degree Mallory connective tissue stain  $\times 400$





(Schroeder and Neumann Arterial hypertension in rats. II)

#### PLATE 15

FIGS 10 and 11 Fig 10, photomicrograph of left kidney and Fig 11, of right kidney of rat G 168 The left renal artery had been partially constricted 61 days previously The animal exhibited cardiac hypertrophy, loss of weight, and convulsions before death In the left kidney there are moderate changes in the arterioles, in the right marked Necrosis of the walls of the arterioles is present only in the right kidney Mallory connective tissue stain  $\times 200$



(Schroeder and Neumann Arterial hypertension in rats. II)

# PLATE 16

FIGS 12 and 13 Fig 12, photomicrograph of section of left kidney, and Fig 13, of right kidney of rat C 17 Cellophane perinephritis had been induced about the left kidney 31 days previously The animal exhibited arterial hypertension Vascular changes occurred in both kidneys to a similar degree There is hyaline degeneration of the walls of the arterioles in both sections Mallory connective tissue stain  $\times 200$



(Schroeder and Neumann Arterial hypertension in rats. II)



# TOXEMIA OF PREGNANCY IN THE GUINEA PIG

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## PLATE 17

(Received for publication, February 13, 1942)

During the last 2 years there has occurred a large number of deaths among the breeding females of our guinea pig stock. The course of the disease, time of occurrence in relation to gestation, and lesions noted at autopsy were similar in practically every instance. Females nearing term, or those recently parturient were usually affected, and after death showed an extremely pale, fatty liver. For want of a better term, we have until recently designated the condition the yellow liver disease of late pregnancy.

Judging from the literature, the condition occurs infrequently. It appears to be identical with that described in guinea pigs by T. Smith (1) and which has been encountered by Nelson (2). Greene (3) has recently studied a condition in rabbits, toxemia of pregnancy, which is of particular interest in connection with the disease we have encountered. He has noted a striking similarity between the disease observed by Nelson in guinea pigs and that occurring in the rabbit. The outbreak in our stock was of considerable severity and differed from those seen by Smith and by Nelson in seasonal incidence.

In view of the infrequent occurrence of the disease and its similarity to toxemia of pregnancy of the rabbit, a report of the findings is submitted.

### *Description of the Colony*

The guinea pig colony consists of about 300 animals, of which about 150 are breeding females. The stock is on the whole, free from the usual guinea pig epidemics, although occasional deaths from pneumonia due to *Bact. bronchiseptica* or pneumococcus occur. During the early months of the period considered in this report, a few animals with Group C streptococcus lymphadenitis were in the herd. This disease has since been eradicated.

In order to prevent the introduction of disease, inbreeding has been practiced for 3 years. The diet consists of Purina complete rabbit chow supplemented with cabbage twice a week. Water is before the animals at all times. The quarters are air-conditioned, the temperature being around 70°F and the humidity about 45 per cent. Each cage contains two or three females and a male. Pregnant animals are removed from the breeding cages about a month prior to parturition.

### *Incidence and Observations on the Sick Animals*

The disease came to our attention early in July, 1940, when nine pregnant dams died revealing livers of a striking yellow color at autopsy. Those first to die five in

number, were among a group of pregnant dams isolated from the herd because of lymphadenitis. During the same month, four additional deaths occurred among the main stock. During August, six more animals succumbed showing the same yellow liver picture. The nine animals dead during July, and the six dead during August of the yellow liver disease represented 50 per cent and 33 per cent, respectively, of the total deaths in the colony during these months. Although careful check was kept on the colony and routine autopsies were performed, no new cases were seen until March, 1941. Four animals died during this month and deaths have continued throughout the summer and up until the present time (December, 1941).

In Table I the total number of deaths occurring in the guinea pig colony monthly from March, 1941, until November, 1941, are given in relation to the number dead showing the yellow liver picture. It is seen in Table I that 47

TABLE I

*Number of Deaths from Yellow Liver Disease in Comparison to Total Number of Deaths from March through November, 1941*

Date	Total death all causes	Dead with yellow liver picture
Mar , 1941	20	4
Apr , 1941	15	2
May, 1941	39	5
June, 1941	28	8
July, 1941	22	3
Aug , 1941	22	4
Sept., 1941	20	4
Oct , 1941	20	5
Nov , 1941	28	10
	214	47

or 21.9 per cent out of a total of 214 deaths from all causes from March through November, 1941, were associated with the yellow liver disease of late pregnancy. At one period, 19 consecutive females coming to term died with characteristic symptoms.

The incidence of the disease is strikingly associated with the latter stages of gestation. Most cases occurred within a week or 10 days before parturition or within a similar period after parturition. A number of animals aborted well developed fetuses and died thereafter with typical signs.

Clinical signs usually appear 2 or 3 days before death occurs. In some cases the onset is sudden and death occurs within 24 hours after the first appearance of signs. A ruffled coat and inappetence is first seen. The animal becomes progressively less inclined to move about, finally becoming prostrate, and showing signs of respiratory distress. For some time before death, the eyes become dull and a yellow crusty mass



forms along the eyelids. In a limited number of cases in which the temperature was taken it was from 1° to 2°C. above normal. To date we have not observed recovery in animals exhibiting typical symptoms.

The occurrence of cases in relation to the time of gestation and multiplicity of pregnancies is shown in Table II. Of the total number of cases shown in this table the majority died. Those killed were prostrate and would have died within a few hours. The number of dams stricken after delivery of young (post-partum or after abortion) is higher than among ante-partum dams. The high incidence of cases among first and second pregnancy dams is of some interest.

TABLE II  
*Cases in Relation to Gestation and Number of Pregnancies*

No. of cases	Died	Dams killed	Ante-partum	Aborted	Post-partum	Primiparous	Multiparous
47	39	8	17	7	23	20	27 { 13 2nd 9, 3rd 3 4th

TABLE III  
*Principal Characteristics Seen on Postmortem Examination*

No. of cases	Abundant fat stores	Yellowed livers	Yellowed kidneys	Normal lungs	Congested lungs	Pneumonic lungs
47	43	47	11	9	20	18

### *Morbid Anatomy*

Animals killed when prostrate or those autopsied soon after death show a constant gross pathology. The principal findings are tabulated in Table III.

There are rich fat accumulations in all the fat depots of the body, especially in the abdominal cavity. The liver has a striking appearance. It is somewhat swollen, friable and feels soapy when handled. In some cases it has been very pale, almost clay colored, more frequently a bright orange yellow. Usually the entire organ is evenly colored, but in a few cases extensive yellow mottling was seen. An interesting observation was made on animals which were killed for examination. Upon being opened, the liver was seen to be pale in relation to normal liver tissue, when the blood vessels supplying the organ were cut and the blood drained out this color quickly faded rendering the liver the typical yellow color seen in animals which had died. Fig. 1 illustrates the characteristic pale liver seen in fatal cases.

Changes in the gall bladder were seen in practically every case. The contents were granular and bright yellow and imparted a yellow color to the bile ducts.

The kidneys of a number of animals were yellowed and the adrenals in a few of these cases were somewhat congested.

In all but nine of the 47 cases studied to date, the yellow liver was associated with changes in the lungs. Well defined edema and congestion over the entire lung area was seen in 20 cases, while in 18 cases frank pneumonic consolidations occurred. The smaller lobes were most frequently involved with or without consolidations of portions of the caudal lobes.

A distinct flabbiness of the heart muscle was noted in a number of cases but this was the exception rather than the general finding. The appearance of the heart blood of many dead animals is of interest in view of the general disorder in fat metabolism which characterizes the disease. When the heart was severed, the right auricle was often filled with a milky fluid which microscopical examination showed consisted of fat globules. A similar observation was made by Greene (4) in rabbits dead of toxemia of pregnancy.

The stomach was usually empty, this finding being readily correlated with the inappetence for some time before death.

The bladder was usually empty or but partially filled. The spleen was normal in all but a few cases in which extensive pneumonia was present. In these, slight enlargement was noted. Fetuses *in utero* in dams dead before parturition appeared to have been dead perhaps a day before the dam's death. The livers of some were pale but on the whole little abnormality was seen among unborn young. Congestion was seen in the walls of the uterus of a number of dams dead antepartum. The mammae were engorged and contained milk in all but a few animals. Those which were not secreting died over a week before the probable date of parturition.

### *Histological Examination*

Tissues were hardened in Zenker's fluid and stained with hematoxylin and eosin. Sections of liver of many animals in the series were studied and marked changes were observed in each case. Widespread fatty infiltration and degeneration were the general finding, but occasionally areas of necrosis and/or hemorrhage were encountered. The fatty changes were widespread and in most cases involved the entire lobule. In a few sections, lesions were confined to the center portion. The fat content of the liver in practically every case examined microscopically was remarkable, the parenchymal cells being virtually loaded with fat globules (Fig. 2).

Microscopic changes in kidney tissue were not frequently seen, although fewer specimens of kidney were examined than of liver. This was unexpected since many of the kidneys taken for section were distinctly pale and fatty looking on gross examination. A number of cases showed well marked fatty degeneration of the tubular structures and occasional cortical necrosis. One instance of extensive necrosis and hemorrhage was seen in the cortex.

Unfortunately, sections were cut from only a small number of the lungs which showed congestion only. In these, however, fat laden alveolar cells such as were described by Smith (1) were seen.

Sections of pneumonic lungs were characteristic of those seen in terminal *Bact. bronchisepticum* or pneumococcus infections in guinea pigs (1).

The heart muscle of the few animals examined histologically showed evidence of degeneration as indicated by swollen, uneven staining strands. Occasionally a necrotic strand was noted. Extreme fatty changes were not seen.

*Attempts to Establish the Cause of the Disease**Infectious Agents*

It was not possible to associate the disease with the presence of a transmissible agent. Attempts to transmit the disease using macerated liver tissue injected intraperitoneally were unsuccessful on three different occasions.

Numerous cultures made of liver tissue on blood agar and in thioglycollate broth (Baltimore Biological Laboratory Company) remained sterile or developed banal types of bacteria which could not be suspected as being of etiological significance.

Cultures made from normal or congested lungs were not significant. Pneumococci or *Bact. bronchisepticum*, and in one instance a bipolar rod, were isolated from pneumonic lungs. Portions of lungs showing the widespread congestion so often encountered were placed in glycerol-saline. Within a week of storage of the first material, specimens from five additional cases were collected. These were ground with sterile sand, made up in 10 per cent suspensions with broth, and centrifuged to remove gross particles. Intrapleural and intralobular injections in 0.25 cc. amounts failed to induce disease.

Cultures made from fetuses or from the uterine contents of freshly dead pregnant dams failed to develop growth.

*Toxic Factors*

Having failed to establish a pathogenic agent in the etiology of the disease, other possibilities were explored. In the early stages of the investigation, experiments were being made in which animal feeds were being treated with carbon tetrachloride. This substance causes liver damage in guinea pigs and, in view of the possibility that portions of the experimental feeds were accidentally given to the main animal stock, attempts were made to reproduce the yellow liver disease by feeding materials treated with carbon tetrachloride vapor and which had not been aired sufficiently to remove all of the gas. Deaths occurred among the animals fed such food but post mortem findings were dissimilar to those dead of the yellow liver disease, notably in the intense inflammatory response of the stomach and upper digestive tract. Furthermore, guinea pigs dead of carbon tetrachloride poisoning failed to show the extensive discoloration of the liver which was characteristic of the yellow liver disease. It appeared that the deaths encountered were not due to carbon tetrachloride poisoning and upon inquiry of the manufacturer of the feed we were advised that carbon tetrachloride was not used in processing it.

*Diet*

Severe fatty degeneration of the liver in the guinea pig occurs when certain diets are fed and fractions of cod liver oil have been established as the cause of

second pregnancies. This is in contrast to the findings in rabbits in which multiparous dams more frequently die. It appears that the guinea pig disease has a higher killing propensity and that the first attack is fatal. It should be repeated that we have not seen recovery of cases which showed characteristic symptoms.

The toxemia in guinea pigs appears to be the result of disorder in fat metabolism, but factors which induce the upset are obscure. Smith discussed the possibility that respiratory embarrassment due to the pressure of the fetus was concerned in causing the disease. Also, that lessened air supply during the winter months might account for the occurrence of cases during this season only. In the latter regard it should be pointed out that our animals were maintained in air-conditioned quarters having a constant supply of air regulated as to temperature and humidity at all times, and cases occurred both during the winter and summer months. Although the symptoms are those of intoxication, no toxic or infectious agent could be incriminated.

No direct evidence has been adduced in this investigation as to the relationship of endocrine disturbance as a factor in causing toxemia of pregnancy in the guinea pig. However, the clinical and pathological similarity of the disease to that studied by Greene in the rabbit which was considered by him to be the result of endocrine disorder, warrants the suggestion that the guinea pig disease has a similar etiology.

#### SUMMARY

The clinical and pathological manifestations of a disease occurring in the late stages of pregnancy or following parturition in the guinea pig are described. The similarity of this disease to toxemia of pregnancy in the rabbit is discussed. The disease appears to be of endogenous origin and is in some way associated with a disordered metabolism occurring at about the time of parturition.

#### BIBLIOGRAPHY

- 1 Smith, T, *J Med Research*, 1913, 29, 291
- 2 Nelson, J B, personal communication
- 3 Greene, H S N, *J Exp Med*, 1938, 67, 369
- 4 Greene, H S N, *J Exp Med*, 1937, 65, 809
- 5 Davis, G, Maynard, L A., and McCoy, C M, *Cornell Univ Agric Exp Station, Bull* 217, 1938
- 6 Taylor, S, *Lancet*, 1937, 232, 973
- 7 Greene, H S N, personal communication

#### EXPLANATION OF PLATE 17

FIG 1 Showing two yellow fatty livers in comparison with one of normal color

FIG 2 Section of liver of a guinea pig dead 48 hours postpartum showing fatty changes. Hematoxylin and eosin  $\times 130$





## THE HYPOPHYSIS AND SECRETION OF INSULIN

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The action of the hypophysis on the pancreas has been demonstrated by a number of *direct and indirect* proofs. The latter, first reported from this Institute, are as follows:

(a) *Complete hypophysectomy* or anterior (distal) lobe removal produces (1) Marked sensitivity to the hypoglycemic and toxic action of insulin and other hypoglycemic agents such as phloridzin, fasting, etc. (2) Reduction of intensity of pancreatic and phloridzin diabetes. (3) A rapid fall in blood sugar and tissue glycogen during fasting, of non pancreatic origin since it occurs after pancreatectomy. The hypoglycemic symptoms can be relieved by prompt administration of glucose, or prevented by a carbohydrate or protein, but not fat diet.

(b) *Anterior pituitary extract* produces the following effects in animals with or without pancreas: (1) Increased resistance to the hypoglycemic and toxic action of insulin and other hypoglycemic agents (phloridzin). (2) Aggravation of diabetes in completely pancreatectomized dogs, with intensified ketosis, acidosis, and rapid death. (3) Strongly increased diabetes in animals without pancreas and hypophysis, in Sandmeyer's partial diabetes, and in phloridzin diabetes of hypophysectomized animals. (4) Production of diabetes in normal dogs, and in dogs with partial pancreatectomy, the ease of production being roughly proportional to the amount of pancreas removed.

In acromegaly the hyperfunction of the anterior pituitary might account for the presence of glycosuria in 32 per cent of the published cases (Atkinson, 1936). Some of these acromegalia showed resistance to insulin which was reduced after partial removal of the pituitary adenoma (Davidoff and Cushing, 1927).

The *direct action* of the hypophysis on the pancreas has been extensively studied after the hypophysectomy and after administration of hypophyseal extracts, with their resultant effects on pancreas weight, cytology of the islands of Langerhans, insulin content, and insulin secretion.

(a) *The pancreas after hypophysectomy* showed an increase of islet tissue in *Triturus viridescens* (Adams and Ward, 1936), rats (Krichesky, 1936), and dogs (Bakay, 1940, Porto, 1941). The insulin content was found to be normal in dogs (Chambers, Sweet and Chandler, 1935) and rats (Haist and Best, 1940) but normal or greater in relation to body weight (Griffiths and Young, 1940). According to Kepinov and Guillaumie (1934, 1935), insulin secretion is increased in the dog, but we have found it to be normal. The hypoglycemic action of systemic blood described by Cowley (1931) was not confirmed in the careful studies of Elena Di Benedetto (1934).

(b) *The effects of hypophyseal extracts* on the pancreas are very different and probably depend on the type of extract, the dose, the time of treatment, the species used both for extract and treatment, and finally, on the relative quantity of pancreas present in the animal.

An hypertrophy and neoformation of islet tissue was obtained in 3 days in the rat by Anselmino, Herold, and Hoffmann (1933) and other species (Anselmino, Herold, and Hoffmann, 1935, Anselmino and Hoffmann, 1933, 1936) Other authors have been unable to obtain such rapid effects, but Richardson and Young (1938) found the amount of island tissue was doubled after 2 or 3 weeks of treatment of rats, with an increased insulin content of 130 to 250 per cent (Marks and Young, 1940*a, b*)

A hypoglycemic action of certain hypophyseal extracts failed to appear after pancreatectomy (Hoffmann and Anselmino, 1933, Steppuhn, 1934, 1935, Harrison and Long 1940) Using pancreatic-jugular anastomoses in the dog, Zunz and La Barre observed increased insulin secretion after pitressin or pitocin (1935 *a*), thyrotropic extracts (1935 *b*), and pancreatotropic extracts (1935 *c*) of the hypophysis. Posterior pituitary extract was without action on insulin secretion after its injection into the pancreatic artery (Foglia, 1931), furthermore, its hyperglycemic activity was the same in normal and in recently pancreatectomized dogs (Houssay and Di Benedetto, 1933)

The diabetogenic action of anterior hypophysis was discovered in this Institute first in the toad without hypophysis and pancreas (Houssay and Biasotti, 1930, 1931) and afterwards in dogs, normal, partially pancreatectomized, or hypophysectomized-pancreatectomized (Houssay, Biasotti, and Rietti, 1932, 1933) The injection of anterior lobe extracts can produce a diabetes which persists after interrupting the injections as was found in dogs with reduced pancreas (Houssay, Biasotti, and Rietti, 1932) or in normal dogs (Young, 1937) After injecting dogs for 3 days with 1.4 gm. per kilo per day of anterior hypophysis extract the pancreas shows a diminished insulin secreting capacity On grafting it to the neck of a pancreatectomized dog it will not lower the high blood sugar as does a graft of a normal dog pancreas (Houssay and Foglia, 1936)

Richardson and Young (1938) and Richardson (1937, 1940) have found that the first signs of damage in the Langerhans' islets are a partial or total disappearance of the granules of the beta cells, hydropic degeneration of these cells, increased mitosis in some of the islets, and vacuolization of the epithelium of the intralobar ducts When diabetes does not appear the only changes are the vacuolization of the epithelium of the ducts and a small decrease of the granules of the B cells When permanent diabetes is produced the islets are transformed into groups of alpha cells with a few altered B cells and, finally, a hyalinization of the islets replaces all the cells or especially the B cells These damages of the B cells have also been found by Campbell and Best (1938), Campbell, Keenan, and Best (1939), Foglia and De Robertis (1939), Loubatieres (1939), Dohan and Lukens (1939), and Dohan, Fish, and Lukens (1941)

Foglia (1939) with De Robertis found that in 5 dogs injected 2 to 4 days with hypophyseal extract (fasting blood sugar 143 to 191 mg per cent) the protoplasm of the B cells was vacuolized, A and B cells were atrophic with a dark cytoplasm and pyknotic nuclei

The diabetogenic extract decreases the insulin content of the pancreas (Campbell



and Best 1938, Campbell *et al.*, 1939, 1940 Best *et al.*, 1939, Marks and Young, 1940*a, b*) The normal insulin content (3 to 4 units per gm.) of the pancreas began to decrease in 24 hours and after 7 days it was as low as 0.14 to 0.47 unit per gm. Eleven days later it was 0.38 in a dog with diabetes and 4.1 units per gm. in another which did not become diabetic. After 7 days of injections the insulin content becomes normal in 4 days (Haist and Best, 1940) In dogs with permanent diabetes the values were of 0.2 unit per gm. or even less and there was no recovery even after 198 days (Best, Campbell, and Haist, 1939)

A simultaneous treatment with protamine-insulin prevents the increase in blood sugar and the glycosuria and also prevents the decrease in the insulin content of the pancreas and the degeneration of the islets (Campbell, Haist, Ham, and Best, 1940) In the partially pancreatectomized cat insulin determines a return to normality of the islets in which hypophyseal extract had produced a hydropic degeneration (Lukens and Dohan, 1940)

The aim of the present work has been to study the insulin secretion of the pancreas of animals either with diabetes produced by hypophyseal extracts or resistant to the extracts. For such purposes those pancreases were grafted by vascular anastomosis to the neck of dogs made diabetic by extirpation of their pancreas. This allowed us to study the capacity of the grafted pancreas to secrete insulin in conditions of overcharge in order to correct a diabetic hyperglycemia

### *Materials and Methods*

The test for pancreatic secretion in the present studies is the blood sugar lowering action of a duodeno-pancreas preparation from various types of donors, connected by vascular anastomoses with the carotid artery and jugular vein of a pancreatectomized recipient.

Both donor and recipient were anesthetized with 0.8 to 0.10 gm. per kilo of chloralose given intravenously. This anesthetic does not markedly alter blood sugar or insulin secretion. All recipients had been pancreatectomized 20 hours previously. The pancreas and part of the duodenum were removed from the donor, leaving intact the coeliac trunk which was connected with the carotid artery of the recipient by means of a Payr cannula. Blood, passing into the graft (maintained at 38–39°C) by the pancreato-duodenal arteries, drained by various veins into a section of portal vein which was joined to the jugular vein of the diabetic recipient. The pancreases were maintained over a thermostat at 38–39°C. between pieces of cotton soaked in saline solution and covered with rubber to prevent evaporation. The pancreas and intestine so maintained have shown a normal aspect after 13 hours according to our experience (Houssay, Lewis, and Foglia, 1928). We did not extend our experiments beyond that time.

The diabetic dog (12 to 17 kilos) had been without a pancreas for 20 to 24 hours (exceptionally for 44 to 48 hours). In the latter cases the blood sugar was 350 to 500 mg. per cent instead of 250 to 300 mg. per cent, so that the time necessary to reach normal levels was greater after grafting.

Blood samples for sugar determination were obtained from the carotid artery before and at intervals after grafting. Experiments were discarded if there was evidence of thrombosis, hemorrhage, or poor circulation in the grafted pancreas, also if the recipient died or showed signs of asphyxia before 6 hours of observation.

The pancreas, grafted to the neck by connecting its blood vessels to the carotid artery and jugular vein, continues to live for 10 to 15 hours. It maintains the blood sugar at a normal level, regulates the formation of muscle and liver glycogen, and responds to humoral stimulation by a graduated secretion of insulin. It increases its secretion when blood sugar is high and decreases it when it is low.

When glucose is injected (1 gm. per kilo intravenously) a blood sugar curve similar to that of normal dogs is obtained. If the graft is removed a curve of the diabetic type is obtained. The physiologic insulin secretion maintains the normal sugar concentration in blood and conversely the sugar concentration regulates the insulin secretion (*cf* Houssay and Deulofeu, 1939). The anesthesia with chloralose does not modify the blood sugar or the insulin secretion.

The donors were of the following types: (1) Hypophysectomized dogs; (2) Normal dogs receiving injections with extract of anterior hypophysis with or without diabetes; (3) Dogs with permanent diabetes produced by injections of anterior hypophysis and persisting after injections were stopped; (4) Dogs maintained in a hyperglycemic state by continuous and prolonged intravenous infusions of glucose.

The anterior hypophyseal extract was prepared weekly from freshly killed beef glands frozen with dry ice ( $\text{CO}_2$ ) for transport to the laboratory. The glands were dissected at low temperature, the anterior lobes separated, and finely ground. Each 800 gm. of gland was added to 2400 ml. of water and 600 ml. of 0.8 per cent NaOH, previously chilled. The container, kept partially submerged in ice water, was repeatedly shaken and then placed in the refrigerator until the following day, when 150 ml. of 0.25 per cent acetic acid was added. After a few minutes 0.8 per cent NaOH was used to bring the solution to a weak alkaline reaction to phenol red. A clear supernatant solution obtained by centrifugation, was divided into 60 ml. portions which were frozen for preservation.

The extract was given intraperitoneally in doses of 7 cc. per kilo per day (1.4 gm. of fresh lobe) in the morning, just after a blood sample for sugar had been obtained from the ear margin. The dogs were kept in metabolism cages to facilitate collection of urine. They were fed 30 to 40 gm. of fresh beef per kilo per day at 2 p.m. Drinking water was not limited.

Chemical analyses were done as follows: blood sugar by Somogyi modification of Hagedorn-Jensen method, urine sugar by Benedict method, and acetone bodies by Van Slyke method.

## RESULTS

*Normal Pancreatic Graft*—The pancreas of a normal dog, intercalated in the circulation of a dog made diabetic by extirpation of its pancreas 20 to 24 hours previously, corrects the hyperglycemia, bringing back and keeping the blood sugar at normal levels. High blood sugar stimulates insulin secretion, which, however, moderates when normal levels are reached (Houssay and Deulofeu, 1939).

Assuming 120 mg per cent as the upper limit of the blood sugar in a normal dog, 13 of 15 cases reached this limit in 3 to 5 hours (Table I and Fig 1) In

TABLE I  
*Duodeno-Pancreatic Vascular Graft from Normal Dogs*

Weight of donor	Blood sugar Hours									Weight of recipient
	Before	½	1	1½	2	3	4	5	6	
kg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	kg
7	294	268	246	210	184	119	98	95	104	—
8	242	213	210	202	188	121	105	82	77	—
7 2	202	185	165	156	124	119	100	111	101	—
14 0	257	265	257	257	225	162	126	119	100	13 5
12 0	352	296	277	239	226	188	127	105	100	13
11 3	280	221	260	217	—	187	160	138	108	12 5
14 0	239	220	205	198	211	205	185	168	159	15 5
16 5	227	197	179	172	136	—	124	97	97	12
12 0	258	224	222	201	192	142	129	98	89	12
12 5	213	180	176	187	173	149	109	100	87	16
11 5	231	216	199	155	126	132	98	95	91	13
10 0	202	219	195	166	135	109	93	90	82	11
12 3	217	227	239	227	193	125	118	113	119	9
11 0	210	178	167	136	127	103	101	103	104	20 5
9 0	239	227	207	174	147	195	111	101	97	17 5

TABLE II  
*Duodeno-Pancreatic Vascular Graft from Hypophysectomized Dogs*

Hypophysectomized dog			Pancrectomized recipient									
Days since operation	Weight	Blood sugar	Weight	Blood sugar Hours								
				Before	½	1	1½	2	3	4	5	6
	kg	mg per cent	kg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1571	11 5	91	17	238	229	224	191	158	119	112	112	100
130	7 5	102	16	265	259	238	213	205	158	124	112	103
88	8 0	102	13 5	232	232	218	215	170	105	98	94	84
88	5 5	94	16 5	253	220	215	200	173	124	115	103	81
144	5 5	82	16 5	278	228	236	217	208	189	189	126	104
31	9 0	97	18 5	253	242	230	221	211	193	157	137	107

one animal it took 6 hours and in another a normal level was not reached. This might be due to either a subnormal insulin secretion of this pancreas, or an insulin resistant recipient.

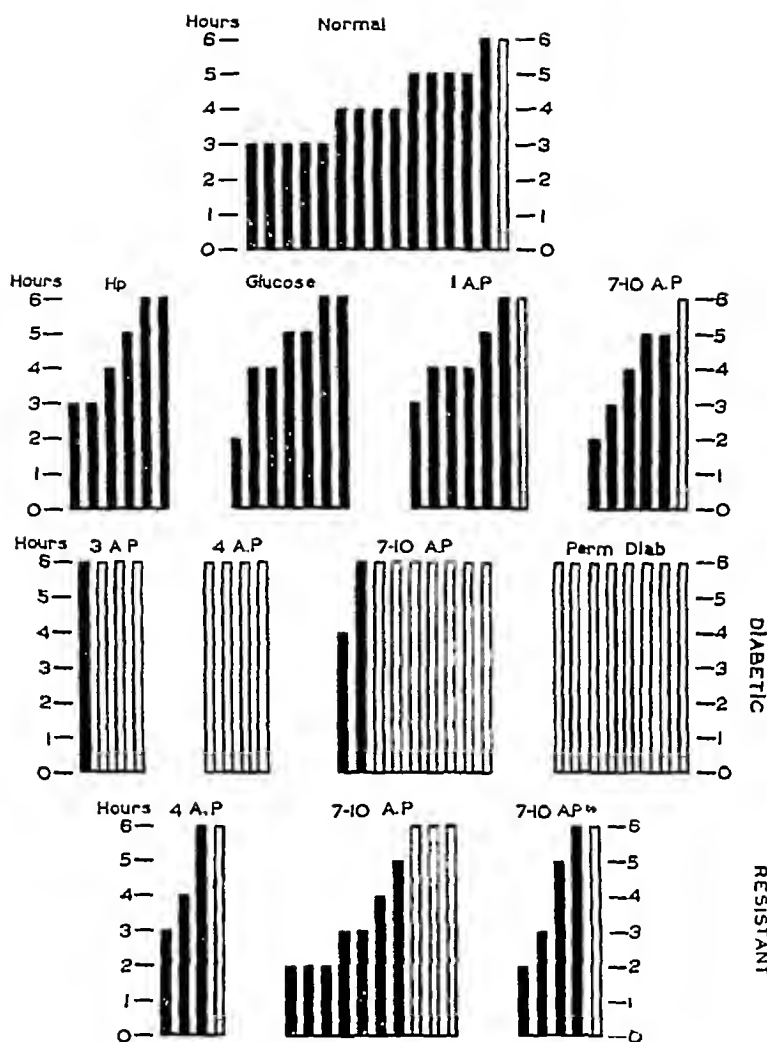


FIG 1 Dogs pancreatectomized 20 hours before and grafted with a duodeno-pancreas. Each black column shows the time in which the blood sugar of the pancreatectomized dog was lowered to 120 mg per cent. The white columns indicate that the blood sugar did not decrease to that level within the 6 hours of experiment. The duodeno-pancreases which were grafted belonged to: First row normal dogs; Second row Hp = hypophysectomized, glucose = injected continuously during 4 days with glucose (average 1 gm per kilo per hour), 1 A.P. = normal dogs with one injection of anterior pituitary extract (1 4 gm per kilo), 7-10 A.P. = injected 7-10 days daily and with diabetes only the last days; Third row 3 A.P., 4 A.P., and 7-10 A.P. = normal dogs injected during 3, 4, or 7-10 days in the same way and which were diabetic; Perm. diab. = diabetic after suspending treatment; Fourth row 4 A.P., 7-10 A.P. = injected 4 or 7-10 days without becoming diabetic (resistant), 7-10 A.P. (1) = injected 7-10 days, diabetic between 2nd and 5th days but with normal blood sugar at the end.

*Pancreatic grafts from hypophysectomized dogs behaved the same as those from normal dogs, since the hyperglycemia of the recipient was corrected in 3 to 6 hours in all 5 cases (Table II and Fig. 1). The donors had been hypophysectomized for from 31 to 1571 days and were in excellent health. One can conclude that there was no demonstrable diminution or increase in the capacity of the pancreas to secrete insulin in the absence of the hypophysis.*

*Diabetic action of anterior pituitary extract is at a maximum after repeated daily injections for 3 to 5 days. Blood sugar in fasting animals 24 hours after an injection varies between 120 to 320 mg per cent (average 176 mg per cent) for several hundred dogs. Hyperglycemia is accompanied by glycosuria,*

TABLE III

*Duodeno-Pancreatic Graft from Donor Dogs Receiving a Single Intraperitoneal Injection of Alkaline Extract of Beef Anterior Pituitary (7 Cc. the Equivalent of 1.4 Gm. of Fresh Gland per Kilo per Day)*

Donor dog			Pancreatectomized recipient									
Weight	Blood sugar		Weight	Blood sugar Hours								
	Before injection	1 day after		Before	½	1	1½	2	3	4	5	6
kg.	mg. per cent	mg. per cent	kg.	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent
10	—	104	15.5	253	239	205	205	207	185	156	129	109
23	98	129	9.0	261	245	241	213	163	136	110	—	—
16.5	105	133	13.5	267	217	189	180	140	110	102	87	98
16.5	106	140	12.2	273	240	231	208	182	142	112	103	93
12.0	93	149	13.0	390*	346	311	290	249	197	177	163	150
12.8	120	156	14.0	265	236	196	178	143	124	111	118	—
15.0	115	166	15.0	232	230	207	200	160	150	138	115	—

\* Pancreatectomized 48 hours before.

increased acetone bodies of blood and urine, and an increased plasma protein. There is also a fall in the alkaline reserve and a slight decrease in plasma chlorides, potassium, and calcium.

If an animal does not eat, the blood sugar fails to rise, or falls if it is high. This indicates that to some extent the hyperglycemia is alimentary. Regardless of the blood sugar level there is an increased resistance to the sugar lowering effect of insulin.

Upon opening the abdomen the omentum appears pink and feels soapy or greasy. The liver appears fatty and has an increased lipid content (Foglia and colleagues, 1937). There is no relation between the fatty appearance of the liver and the blood sugar level.

*Pancreatic Grafts from Dogs Receiving Anterior Pituitary Extract —(a) Dogs*

TABLE IV

*Duodeno-Pancreatic Vascular Graft from Dogs That Had Received Injections of Alkaline Extract of Beef Anterior Pituitary for 3 or 4 Days (7 Cc the Equivalent of 1.4 Gm of Fresh Lobe per Kilo per Day)*

Donor dogs							
Experiment No	Weight	No. of injections	Blood sugar Days				
			Before injection	1	2	3	4
	kg		mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	—	3	90			149	
2	—	3	98			187	
3	—	3	89			251	
4	—	3	94			322	
5	7	4	91	—	150	119	150
6	9.5	4	86	100	137	150	196
7	7	4	88	—	266	100	113
8	9.5	4	110	163	205	223	320
9	10	4	96	131	103	100	108
10	11.5	4	105	111	—	—	121
11	12	4	96	105	99	93	135
12	10	4	109	93	—	—	140

Recipient dogs										
Experiment No	Weight	Blood sugar Hours								
		Before	½	1	1½	2	3	4	5	6
	kg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	12	293	278	274	246	262	268	242	246	242
2	10.2	375	325	280	224	190	151	123	122	110
3	10	282	218	230	222	218	246	268	248	—
4	14	278	212	212	182	142	134	184	154	136
5	16	512	474	474	478	466	422	396	300	292
6	15	275	236	226	211	217	232	205	205	221
7	17	258	212	235	214	195	309	288	241	—
8	12.8	380	362	362	350	350	300	328	204	—
9	22	244	216	200	198	—	144	126	122	106
10	—	217	210	206	171	139	131	100	100	110
11	15	265	243	243	257	240	226	191	164	156
12	—	219	187	149	146	130	108	95	73	77

*receiving one injection* The pancreas from 6 of 7 animals can be considered normal, since the blood sugar of the recipient was lowered to 120 mg per cent or less in 3, 4, 4, 4, 5, and 6 hours in dogs with blood sugars of 133, 129, 140, 156, 104, and 166 mg per cent respectively (Table III). In the remaining

animal, which had been without pancreas for 48 hours, the high value of 390 mg per cent was reduced to 150 mg per cent in 6 hours

TABLE V

*Duodeno-Pancreatic Graft from Dogs That Had Received Injections of Alkaline Extract of Beef Anterior Pituitary for 7 to 10 Days (7 Cc. Equivalent of 1.4 Gm. of Fresh Lobe per Kilo per Day) Hyperglycemia of 150 Mg. Per Cent or More Present from 2nd to 4th Day and at Time of Transplanting the Pancreas to the Neck of the Recipient*

## Donor dogs

Experiment No.	Weight	No. of injections	Blood sugar										
			Days										
			Before	1	2	3	4	5	6	7	8	9	10
	kg		mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	8	8	78	101	139	—	152	125	100	127	194	—	—
2	8	10	78	78	100	—	182	—	195	242	127	155	162
3	7	8	103	127	122	152	101	—	123	151	151	—	—
4	8	8	88	118	160	121	150	106	110	—	164	—	—
5	6	9	72	86	118	123	162	124	167	126	126	154	—
6	—	9	91	107	155	174	131	106	—	119	139	214	—
7	9.5	7	118	121	—	160	169	202	186	312	—	—	—
8	9.5	8	82	133	—	114	177	151	135	155	137	—	—
9	8	8	102	130	182	—	116	195	202	186	257	—	—

## Diabetic recipients

Experiment No.	Weight kg	Blood sugar								
		Hours								
		Before	½	1	1½	2	3	4	5	6
		mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	17	245	244	209	207	198	158	145	138	124
2	20	255	255	244	202	168	158	160	155	148
3	12.5	385	347	347	310	316	289	223	207	—
4	16.5	283	242	217	178	175	186	180	148	148
5	17.5	429	407	397	304	287	224	224	211	215
6	20.5	320	294	294	246	222	161	116	93	72
7	12	293	289	271	253	255	193	139	134	109
8	13.5	527	489	489	414	338	320	332	332	—
9	22	261	223	221	217	223	184	169	178	200

(b) Dogs receiving 3 injections and having a marked diabetes (Table IV) yielded pancreatic grafts that had a diminished insulin secretion since the hyperglycemia of the recipient was restored to a normal level in only 1 of 4 cases.

(c) *Dogs receiving 4 injections* fell into 2 groups of 4 animals each. In one group the blood sugars rose to 150, 196, 266, and 320 mg per cent. The pancreas grafts from these dogs failed to secrete enough insulin to restore to normal levels the hyperglycemia of their recipients (Table IV). In the other 4 dogs the blood sugar rose to only 108, 121, 135, and 140 mg per cent. Pancreas grafts from these animals secreted more insulin than in the previous

TABLE VI

*Duodeno Pancreatic Graft from Dogs That Received Injections of Alkaline Extract of Beef Anterior Pituitary for 7 to 10 Days (7 Cc the Equivalent of 1.4 Gm of Fresh Gland per Kilo per Day). These Donors' Hyperglycemia of the 2nd to 5th Day Had Fallen at the Time of Grafting*

Donor dogs												
Experiment No	Weight	No of injections	Blood sugar									
			Days									
			Before	1	2	3	4	5	6	7	8	9
	kg		mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	6	9	80	115	112	117	188	175	—	95	100	124
2	6	9	83	135	127	118	—	137	152	111	115	120
3	8	9	82	122	126	185	231	275	—	120	130	127
4	7	7	96	98	—	178	147	151	114	134	—	—
5	7	8	78	151	150	151	92	—	119	149	140	—

Diabetic recipients										
Experiment No	Weight	Blood sugar								
		Hours								
		Before	½	1	1½	2	3	4	5	6
	kg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	20	282	237	161	121	88	86	89	78	75
2	14.5	265	246	208	175	146	111	88	77	—
3	12	212	199	195	181	178	136	130	120	111
4	16	227	210	210	208	190	183	154	122	104
5	14	328	320	291	261	202	193	191	207	—

hypophyseal diabetic groups, as shown by 3, 4, and 6 hours restoration periods in 3 of them. One failed to reach normal levels in 6 hours (Table III).

(d) *Grafts from dogs receiving 7 or more injections* of anterior pituitary extract are divided into 4 groups. There were 9 animals that had a high blood sugar the 2nd to the 5th day up to the moment of the graft (Table V). In these the secretion of insulin was diminished in 7 cases, slightly diminished in 1, and nearly normal in 1.



TABLE VII

*Duodeno-Pancreatic Graft from Dogs That Received Injections for 7 to 10 Days of Alkaline Extract of Beef Anterior Pituitary (7 Cc the Equivalent of 1.4 Gm. of Fresh Gland per Kilo per Day)*  
*In These Resistant Donors the Blood Sugar Failed to Rise above 150 Mg. Per Cent at Any Time*

Donor dogs													
Experiment No.	Weight	No. of Injections	Blood sugar										
			Days										
			Before	1	2	3	4	5	6	7	8	9	10
	kg		mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent
1	7.5	9	98	98	106	95	91	107	—	103	107	112	—
2	10	8	90	—	124	—	—	121	128	116	127	—	—
3	7	7	85	123	—	130	114	106	122	131	—	—	—
4	8	8	96	—	102	—	—	136	135	102	105	—	—
5	11	21	84	114	89	102	—	126	129	122	118	103	115*
6	8	8	110	144	137	—	139	100	118	116	145	—	—
7	7.3	10	102	100	112	138	121	135	124	—	117	140	132
8	7.5	7	80	100	—	91	122	103	103	147	—	—	—
9	8	7	94	121	96	121	119	119	138	127	—	—	—
10	9.5	8	80	—	149	146	—	131	101	99	116	—	—

## Diabetic recipients

Experiment No.	Weight	Blood sugar									
		Hours									
		Before	1/4	1	1 1/2	2	3	4	5	6	
	kg	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent	mg. per cent
1	15.5	276	248	187	122	118	96	105	98	82	
2	14	229	226	208	143	118	113	88	86	79	
3	24	290	250	218	158	110	83	74	84	69	
4	14	222	205	205	205	163	120	100	88	—	
5	9.5	248	235	229	182	168	117	91	—	—	
6	10.5	254	224	194	188	161	143	120	122	105	
7	14	229	208	197	191	171	153	148	104	91	
8	12	268	288	266	220	231	190	144	136	125	
9	12.5	362	303	299	275	273	249	184	170	161	
10	14	292	235	237	224	209	179	165	148	207	

\* Up to the 21st day blood sugar varied between 84 and 117 mg. per cent values for the last 3 days were 85, 104, and 108 mg. per cent.

In 5 dogs the blood sugar rose to 150 mg. per cent or more between 2 to 5 days, but fell at the time of pancreatic grafting (Table VI). In 2 animals the insulin secretion was normal, in 1 supernormal, in 1 subnormal, and the last definitely inadequate.

Ten dogs injected with anterior pituitary were resistant to its diabetogenic action (Table VII) and in these insulin secretion was found to be supernormal in 3 cases, normal in 4, and subnormal in 3 cases

In 6 dogs the blood sugar rose only at the end of the period of injections, *i e.*, at the time of making the graft. In 1 the insulin secretion was supernormal, in 4 normal, and in 1 subnormal (Table VIII)

TABLE VIII

*Duodeno-Pancreatic Graft from Dogs That Received Injections for 7 to 10 Days of Alkaline Extract of Beef Anterior Pituitary (7 Cc the Equivalent of 1.4 Gm. of Fresh Gland per Kilo per Day) The Donors' Blood Sugar Remained Low until the Last Few Days before Grafting*

Donor dogs												
Experiment No	Weight	No of injections	Blood sugar Days									
			Before	1	2	3	4	5	6	7	8	9
	kg		mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	7.5	9	79	104	134	125	126	144	122	—	154	228
2	8	8	99	109	114	—	152	109	126	104	167	—
3	7	7	94	125	—	109	111	123	172	144	—	—
4	10.5	8	78	85	115	—	108	81	136	143	203	—
5	6	8	98	100	89	—	116	126	112	146	177	—
6	8.5	9	62	70	95	—	89	119	125	133	257	216

Diabetic recipients										
Experiment No	Weight	Blood sugar Hours								
		Before	½	1	1½	2	3	4	5	6
	kg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	12.5	228	211	169	126	101	98	87	62	62
2	16	256	207	201	183	145	108	92	96	89
3	24	239	220	220	163	147	122	94	87	85
4	17	245	194	174	203	180	153	135	106	100
5	20	273	247	219	218	187	142	125	111	117
6	8.5	297	297	287	221	189	157	139	141	128

(e) *Duodeno-pancreatic grafts from dogs with permanent diabetes* In our experience it is exceptional to obtain dogs with permanent diabetes if the pancreas is intact. When anterior pituitary injections raised blood sugar in 2 to 3 days it is easy to maintain an elevation of 200 to 300 mg per cent but this falls to normal levels a few days after stopping injections.

To overcome this difficulty we used dogs with pancreas reduced to half by

removal of the splenic tail and the free duodenal portion. In these it is easy to obtain and maintain diabetes with lower doses of extracts. We prepared many of these dogs. Several died with intense diabetes, acidosis, and coma, in most of them the blood sugar descended a few days after stopping injections.

Grafts from 7 dogs whose diabetes persisted for 8 to 21 days after cessation of injections showed no ability to correct the hyperglycemia of the recipient during 6 hours of observation (Table IX). This indicates that the insulin secretion is small or completely absent. On the other hand, the pancreas from normal dogs with reduced volume to the half, showed a capacity to reduce hyperglycemia to normal level within 6 hours in 7 of 15 cases.

TABLE IX

*Duodeno-Pancreatic Grafts from Donor Dogs Which Had 50 Per Cent Reduced Pancreas and Had Developed Permanent Diabetes after Daily Injection of Alkaline Extract of Fresh, Beef Anterior Hypophysis the Diabetes Persisting after Cessation of Injections. Hyperglycemia of Diabetic Recipient Was Not Reduced to Normal Even after 6 Hours*

Blood sugar of injected dogs	At the time of grafting	Days injected	Days without injection	Weight		Blood sugar of diabetic	
				Donor	Recipient	Recipient at the time of grafting	6 hrs. after grafting
mg per cent	mg per cent			kg	kg	mg per cent	mg per cent
208-480	303	16	8	7	17	223	167
125-360	165	15	8	7.5	13	577	557
259-313	191	90	8	6.7	14	244	231
308-354	217	131	13	8	17	194	189
292-415	371	11	11	10	15	248	205
237-311	312	20	11	9	12	256	205
207-370	354	17	21	7	21	211	208

The histologic examination of the pancreas of dogs with permanent diabetes showed pronounced lesions of the B cells of the islands with degranulation, vacuolization, or complete disappearance.

### RÉSUMÉ AND DISCUSSION

There is no proof of a constant physiologic action of the anterior hypophysis on the pancreas, because (1) the insulin secretion of the hypophysectomized dog is normal, (2) no atrophic lesions have been observed in the islands of Langerhans, on the other hand they are more developed (Porto, 1941). There is also no proof for the existence of a pancreatotrophic anterior pituitary secretion which stimulates or maintains the anatomy or function of these islands.

There is a definite physiologic antagonism well demonstrated between the functions of the anterior pituitary and the pancreas in respect to carbohydrate metabolism. After removal of the hypophysis one may observe (1) a marked sensitivity to insulin, (2) diminution of the intensity of pancreatic or phloridzin diabetes. On the other

hand, an excess of anterior pituitary secretion produces (1) a marked resistance to the action of insulin, and (2) intensification of pancreatic or phloridzin diabetes and a diabetic state in normal dogs

In all species of animals lower doses of pituitary extract will produce diabetic symptoms in proportion to the reduction of pancreatic volume. Conversely, insulin injections inhibit or make more difficult the production of diabetic symptoms with anterior pituitary extract and accelerate their disappearance after discontinuing the treatment with the extract.

Anterior pituitary extract produces two effects on the pancreas which are apparently antagonistic, it may stimulate or alter them. In certain species as in the rat, which is resistant to the diabetogenic action, the stimulating action is more apparent with hyperplasia of the islands and the increase of insulin. After extirpation of the pancreas in the rat it is easy to observe the diabetic action. In the toad the protective rôle of the pancreas against pituitary extract is very great, and it is impossible to produce the diabetic action in normal or hypophysectomized animals, but on removal of the pancreas they become extremely sensitive.

The pancreas of the dog is easily altered by pituitary extract which produces diabetes, lesions of the cells of the islands, and diminishes insulin secretion.

The action in the rat and the dog are contradictory, in the rat the extract stimulates the pancreas and in the dog it is inhibited. In reality both actions exist in both species, since one can produce a transitory or permanent diabetes in a rat by partial pancreatectomy, and in the dog in a certain number of cases diabetes fails to appear and on the contrary there is stimulation of insulin secretion as has been described in this paper.

The diabetic action of the anterior pituitary depends on 3 factors (a) the dose and activity of the extracts, (b) the extrapancreatic factors, and (c) pancreatic factors. The extrapancreatic factors are very important and their existence is shown as follows: (1) anterior pituitary extract produces a marked resistance to the action of insulin (Houssay and Potick, 1929, Di Benedetto, 1932, 1933), injected or from pancreatic graft (Houssay and Foglia, 1936), (2) the diabetic action of the anterior pituitary reaches its maximum intensity in dog or toad without pancreas or hypophysis which is more evident in the absence of the antagonistic action of the pancreas to the pituitary, (3) the hypophysectomized dogs with or without pancreas are extremely sensitive to the hypoglycemic action of insulin. Finally, we may state that anterior pituitary extract produces an increased resistance to insulin but there is no hyperglycemia if the animal does not eat, (4) anterior pituitary extract aggravates the diabetes of a pancreatectomized dog which dies in acidosis and coma, (5) anterior pituitary extract does not produce hyperglycemia in the hepatectomized toad without hypophysis and pancreas (Campos, Curutchet, and Lanari, 1933).

The pancreatic factor in hypophyseal diabetes is manifest in the diminished endocrine function of the islands as follows: (1) The pancreas is able to secrete less insulin than that from a normal animal first observed by Houssay and Foglia (1936) and amply confirmed in this paper. (2) There are cytological lesions of the island cells as shown by Young and Richardson (1937, 1938) and confirmed by Foglia and De Robertis (1939) and Porto (1941). (3) There is a diminished insulin content of the pancreas (Campbell and colleagues, 1938-1940). In our judgment it is more im-

portant to measure the secretion of an organ rather than its contents at death, since the latter does not indicate the secretory intensity, as, for example, in hyperthyroidism. There is an increased secretion of thyroid iodine and yet a diminished iodine content of the thyroid gland.

In the light of all these factors the following interpretation of our experiments is permitted. When anterior pituitary injections produce a diabetes with 3, 4, 7, or more injections, one observes in the pancreas a marked diminution of the capacity to secrete insulin which fails to correct hyperglycemia when grafted into the neck of the pancreatectomized dogs with diabetes. This, we have observed in 14 of the 17 cases studied. In the remaining 3, the diabetes might be due exclusively to extrapancreatic action, whereas in the 14 there was diminution of the insulin secretion. If we include the 6 dogs with permanent diabetes we reach a total of 20 out of 23 cases in which there is an insufficient secretion of insulin to correct the diabetic hyperglycemia.

When animals are hyperglycemic during the first 2 to 5 days with subsequent fall in blood sugar one observes that the pancreatic secretion improves since in 5 cases studied 2 were normal, 1 supernormal, 1 slightly subnormal, and only 1 was definitely inadequate.

In animals resistant to anterior pituitary extract whose blood sugar rises little or not at all, one could observe that in 6 cases insulin secretion was normal, in 3 cases it was definitely supernormal since it corrected the hyperglycemia in only 2 hours, in 1 case there was a slow restoration, and in only 4 cases of these 14 did we observe a diminished secretion. In some of them there were intense lesions of the islands of Langerhans and there must, therefore, have existed extrapancreatic factors which impeded the appearance of diabetes.

In 6 dogs resistant for 6 to 8 days with a terminal rise in blood sugar on the day of grafting, there was normal secretion of insulin in 4 cases, supernormal in 1, and diminished secretion in 1 (Table VIII). The final increase in blood sugar appears, therefore, to be due to extrapancreatic factors.

In dogs receiving only 1 injection of extract there was no alteration of the capacity of the pancreas to correct the hyperglycemia of the recipient, nevertheless, in 3 cases the blood sugar of the donor was 149, 156, 166 mg per cent (Table III). In the last two groups of dogs mentioned the diabetes lasted only 1 day and did not impair the insulin secreting capacity of the pancreas. The blood sugar rise appears to be due to extrapancreatic factors.

The elevation of blood sugar alone by continuous injection of glucose was not sufficient to alter the pancreas during the short period of our experiments, although the blood sugar had been kept for 4 days at a level similar to that observed in dogs with anterior pituitary diabetes, nevertheless, the pancreas of these dogs demonstrated a normal functional capacity to correct the diabetes of the recipients (Table X). Histologically, there is hyperplasia of the islands and signs of hyperfunction of the B cells as observed by Porto.

hand, an excess of anterior pituitary secretion produces (1) a marked resistance to the action of insulin, and (2) intensification of pancreatic or phloridzin diabetes and a diabetic state in normal dogs

In all species of animals lower doses of pituitary extract will produce diabetic symptoms in proportion to the reduction of pancreatic volume. Conversely, insulin injections inhibit or make more difficult the production of diabetic symptoms with anterior pituitary extract and accelerate their disappearance after discontinuing the treatment with the extract.

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The pancreas of the dog is easily altered by pituitary extract which produces diabetes, lesions of the cells of the islands, and diminishes insulin secretion.

The action in the rat and the dog are contradictory, in the rat the extract stimulates the pancreas and in the dog it is inhibited. In reality both actions exist in both species, since one can produce a transitory or permanent diabetes in a rat by partial pancreatectomy, and in the dog in a certain number of cases diabetes fails to appear and on the contrary there is stimulation of insulin secretion as has been described in this paper.

The diabetic action of the anterior pituitary depends on 3 factors (a) the dose and activity of the extracts, (b) the extrapancreatic factors, and (c) pancreatic factors. The extrapancreatic factors are very important and their existence is shown as follows: (1) anterior pituitary extract produces a marked resistance to the action of insulin (Houssay and Potick, 1929, Di Benedetto, 1932, 1933), injected or from pancreatic graft (Houssay and Foglia, 1936), (2) the diabetic action of the anterior pituitary reaches its maximum intensity in dog or toad without pancreas or hypophysis which is more evident in the absence of the antagonistic action of the pancreas to the pituitary, (3) the hypophysectomized dogs with or without pancreas are extremely sensitive to the hypoglycemic action of insulin. Finally, we may state that anterior pituitary extract produces an increased resistance to insulin but there is no hyperglycemia if the animal does not eat, (4) anterior pituitary extract aggravates the diabetes of a pancreatectomized dog which dies in acidosis and coma, (5) anterior pituitary extract does not produce hyperglycemia in the hepatectomized toad without hypophysis and pancreas (Campos, Curutchet, and Lanari, 1933).

The pancreatic factor in hypophyseal diabetes is manifest in the diminished endocrine function of the islands as follows: (1) The pancreas is able to secrete less insulin than that from a normal animal first observed by Houssay and Foglia (1936) and amply confirmed in this paper. (2) There are cytological lesions of the island cells as shown by Young and Richardson (1937, 1938) and confirmed by Foglia and De Robertis (1939) and Porto (1941). (3) There is a diminished insulin content of the pancreas (Campbell and colleagues, 1938-1940). In our judgment it is more im-

hyperglycemia aggravates probably the lesions of the pancreatic cells impaired by the damaging action of the extract.

The functional alteration of the islands can persist in animals with intense diabetes even after cessation of pituitary injections. In many cases the

TABLE VI  
Summary of Tables I to V

Pancreas from the following types of donors	No. of recipient in which the glycemia fell to 120 mg. per cent or less Hours						Total No. of experiments
	2	3	4	5	6	More than 6	
Normal	—	5	4	4	1	1	15
Hypophysectomized	—	2	1	1	2	—	6
With 1 injection of anterior hypophysis extract	—	1	3	1	1	1	7
With 7 to 10 injections of anterior hypophysis extract. Diabetes final day only	1	1	1	2	—	1	6
With 3 injections of anterior hypophysis extract, diabetic	—	—	—	—	1	3	4
With 4 injections of anterior hypophysis extract, diabetic	—	—	—	—	—	4	4
With 7 to 10 injections anterior hypophysis extract, diabetic from 2nd to 5th day to end	—	—	1	—	1	7	9
With permanent diabetes	—	—	—	—	—	8	8
Total in these four definitely diabetic groups	—	—	1	—	2	22	25
With 4 injections anterior hypophysis extract. No diabetes	—	1	1	—	1	1	4
With 7 to 10 injections anterior hypophysis extract. No diabetes	3	2	1	1	—	3	10
Total in these 2 non-diabetic groups	3	3	2	1	1	4	14
With 7 to 10 injections anterior hypophysis extract, diabetes from 2nd to 5th day but not at end	1	1	—	1	1	1	5
Continuous intravenous injection of glucose, 4 days.	1	—	2	2	2	—	7
Total No. of donors 82 equal No. of recipients	—	—	—	—	—	—	84

Dogs were considered diabetic when the blood sugar was higher than 150 mg. per cent.

diabetes gradually disappears with an histological improvement in the islands, but in some a permanent diabetic state may persist.

The histological study of the pancreases of the present animals and others from similar conditions was done by Dr. Porto (1941). He has found a parallelism between insulin secretion, hyperglycemia, and the cytologic conditions of the

Supporting the fact that hyperglycemia is not the only factor to consider, in phloridzin diabetes the pancreas has a diminished insulin secretion (Houssay and Foglia, 1936), and recently Porto has found lesions in the B cells of the islands

TABLE X

*Duodeno-Pancreas of Dogs Which Were Injected Continuously with Glucose (50 Per Cent in Physiological Saline Solution 1 Gm per Kilo per Hour Intravenously) Grafted to the Neck of Pancreatectomized Dogs*

Donor dog									
Experiment No	Weight	Glucose	Glucose total in 4 days	Blood sugar Days					
				Before	1	2	3	4	
	kg	gm	gm	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	9	1 62	1400	98	124	170	307	271	
2	8 5	1 83	1500	96	277	185	139	222	
3	10	1 14	1100	94	98	111	163	202	
4	9 5	1 00	900	109	158	264	148	196	
5	8 5	0 86	700	97	126	125	299	335	
6	9 5	0 77	700	94	80	143	212	149	
7	9	1 80	1550	95	158	149	188	131	

Pancreatectomized recipient										
Experiment No	Weight	Blood sugar Hours								
		Before	½	1	1½	2	3	4	5	6
	kg	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent	mg per cent
1	14	206	202	160	87	86	75	73	66	68
2	14	253	221	202	182	150	141	128	113	113
3	17	232	246	236	219	193	202	154	132	118
4	17 5	333	321	280	231	216	176	158	135	120*
5	15 5	250	231	203	201	163	121	103	89	91
6	17	220	190	174	149	133	129	124	120	110
7	16	260	231	209	176	156	121	114	109	107

\* This pancreas showed small hemorrhages during the transfusion

The damaging action on the islets might be due to (1) a direct action as is also produced on other tissues, (2) the persistent increase in blood sugar, (3) the increased secretion of insulin which becomes necessary because of the insulin resistance

Anterior pituitary extract damages the island cells and diminishes insulin secretion. The rise in blood sugar is first due to extrapancreatic activity, this



hyperglycemia aggravates probably the lesions of the pancreatic cells impaired by the damaging action of the extract.

The functional alteration of the islands can persist in animals with intense diabetes even after cessation of pituitary injections. In many cases the

TABLE XI  
Summary of Tables I to V

Pancreas from the following types of donor	No. of recipient in which the glycemia fell to 150 mg. per cent or less Hours						Total No. of experiments
	2	3	4	5	6	More than 6	
Normal	—	5	4	4	1	1	15
Hypophysectomized	—	2	1	1	2	—	6
With 1 injection of anterior hypophysis extract	—	1	3	1	1	1	7
With 7 to 10 injections of anterior hypophysis extract. Diabetes final day only	1	1	1	2	—	1	6
With 3 injections of anterior hypophysis extract, diabetic.	—	—	—	—	1	3	4
With 4 injections of anterior hypophysis extract, diabetic.	—	—	—	—	—	4	4
With 7 to 10 injections anterior hypophysis extract, diabetic from 2nd to 5th day to end	—	—	1	—	1	7	9
With permanent diabetes	—	—	—	—	—	8	8
Total in these four definitely diabetic groups	—	—	1	—	2	22	25
With 4 injections anterior hypophysis extract. No diabetes	—	1	1	—	1	1	4
With 7 to 10 injections anterior hypophysis extract. No diabetes	3	2	1	1	—	3	10
Total in these 2 non-diabetic groups	3	3	2	1	1	4	14
With 7 to 10 injections anterior hypophysis extract, diabetes from 2nd to 5th day but not at end	1	1	—	1	1	1	5
Continuous intravenous injection of glucose, 4 days.	1	—	2	2	2	—	7
Total No. of donors 82, equal No. of recipients	—	—	—	—	—	—	84

Dogs were considered diabetic when the blood sugar was higher than 150 mg per cent.

diabetes gradually disappears with an histological improvement in the islands, but in some a permanent diabetic state may persist.

The histological study of the pancreases of the present animals and others from similar conditions was done by Dr Porto (1941). He has found a parallelism between insulin secretion, hyperglycemia, and the cytologic conditions of the

- Foglia, V G , Trabajo de Adscripcion, Facultad de Medicina, Buenos Aires, 1939
- Foglia, V G , Gerschman, R., Morenzi, A. J , Munez, J M , and Rietti, C T , *Rev Soc argent biol* , 1937, 13, 83, *Compt rend Soc biol* , 1937, 126, 152
- Gayet, R , and Guillaumie, M , *Compt rend Soc biol* , 1928, 98, 676
- Griffiths, M , and Young, F G , *Nature*, 1940, 146, 266
- Haist, R. E , and Best, C H , *Science*, 1940, 91, 410
- Harrison, H C , and Long, C N H , *Endocrinology*, 1940, 26, 971
- Hoffmann, F , and Anselmino, K. J , *Klin Woch* , 1933, 12, 1436
- Houssay, B A., and Biasotti, A , *Rev Soc argent biol* , 1930, 6, 8, *Compt rend Soc biol* , 1930, 104, 407, *Arch ges Physiol* , 1931, 227, 239
- Houssay, B A , Biasotti, A., Di Benedetto, E , and Rietti, C T , *Rev Soc argent biol* , 1932, 8, 563, *Compt rend Soc biol* , 1933, 112, 494
- Houssay, B A , Biasotti, A , and Rietti, C T , *Bol Acad méd Buenos Aires*, 1932, 171
- Houssay, B A , Biasotti, A., and Rietti, C T , *Rev Soc argent biol* , 1932, 8, 469, *Compt rend Soc biol* , 1932, 111, 479, *Compt rend Soc biol* , 1933, 112, 497
- Houssay, B A , and Deulofeu, V , *Ergebn Vitamin-u Hormonforsch* , 1939, 2, 299
- Houssay, B A , and Di Benedetto, E , *Rev Soc argent biol* , 1933, 9, 360, *Compt rend Soc biol* , 1933, 114, 795
- Houssay, B A , and Foglia, V G , *Rev Soc argent biol* , 1936, 12, 237, *Compt rend Soc biol* , 1936, 123, 824
- Houssay, B A , Lewis, J T , and Foglia, V G , *Rev Soc argent biol* , 1928, 4, 859
- Houssay, B A , and Potick, D , *Rev Soc argent biol* , 1929, 5, 66, *Compt rend Soc biol* , 1929, 111, 940
- Kepinov, L , and Guillaumie, M , *Compt rend Soc biol* , 1934, 115, 1564
- Kepinov, L , and Guillaumie, M , *Compt rend Soc biol* , 1935, 119, 149
- Krichesky, B , *Proc Soc Exp Biol and Med* , 1936, 34, 126
- Loubatieres, A , *Compt rend Soc biol* , 1939, 132, 384
- Lukens, F D W , and Dohan, F C , *Science*, 1940, 92, 222
- Marks, H P , and Young, F G , *Lancet*, 1940a, 1, 493
- Marks, H P , and Young, F G , *Nature*, 1940b, 146, 31
- Porto, J , *Rev Soc argent biol* , 1940, 17, 351
- Porto, J , *Rev Soc argent biol* , 1941, in press
- Richardson, K. C , *J Physiol* , 1937, 91, 352
- Richardson, K C , *Proc Roy Soc Med* , 1940, 128 B, 153
- Richardson, K C , and Young, F G , *Lancet*, 1938, 1, 1098
- Steppuhn, O , *Wien Arch inn Med* , 1934, 26, 87
- Steppuhn, O , and Petrowa, *Vechnik Endokrin* , 1935, 5, 478
- Young, F G , *Lancet*, 1937, 2, 372
- Zunz, E , and La Barre, J , *Arch internat physiol* , 1935a, 41, 538
- Zunz, E , and La Barre, J , *Arch internat physiol* , 1935b, 42, 1
- Zunz, E , and La Barre, J , *Arch internat physiol* , 1935c, 42, 95

# THE EFFECT OF EXTERNAL TEMPERATURE ON THE COURSE OF INFECTIOUS MYXOMATOSIS OF RABBITS

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It has been shown by one of us (1) that exposure of rabbits continuously to a high external temperature modifies very markedly the course of infectious myxomatosis. The experiments here reported were undertaken in a continuation of these observations and were designed to measure more exactly the effect of external temperature on the course of infectious myxomatosis, and to obtain information as to the reaction of animals convalescent from infection when they were subjected to reinoculation with active virus. Observations were made also on the development of precipitating and protective antibodies in the serum of recovered animals.

## *Materials and Methods*

*Virus*—The strain of myxoma virus used was derived from one secured originally from Dr T. M. Rivers. In order to avoid variability in dosage which might follow the use of virus contained in a tissue emulsion due to presence therein of viral clumps, the virus was employed in the form of a suspension of elementary bodies in 0.004 M buffer solution which had a pH of 7.2. These viral suspensions were made according to the technique of Rivers and Ward (2) except that after the first passage on the skin a suspension of elementary bodies was used for inoculation rather than the virus contained in a suspension of infected tissue. At the time of these experiments, the virus had been subjected to not more than fifteen such dermal passages. The virus was highly virulent for rabbits infection leading to death in all but 3 to 5 per cent of animals.

*Titration of Virus*—For purposes of titration serial tenfold dilutions of virus were made in Locke's solution. Four or five insertions of each were made intradermally in a rabbit in a volume of 0.1 cc. The animals were observed daily and the presence or absence of lesions was determined. Because infection with this virus under normal conditions is uniformly characterized by the development of secondary lesions, the observations made on the day before the appearance of these (usually the 5th or 6th day after inoculation) were used in computing the viral titer. When in the animals exposed to high temperatures no secondary lesions appeared, the time of maximal development of lesions was selected for calculation. The calculations of titer were made according to the method of Muench and Reed (3), that dilution being chosen as end point which should give rise on multiple inoculation to an equal number of positive and negative results.

*Rabbits*—The rabbits were of various breeds. In order to avoid cross infection

with vaccinia, only rabbits which were convalescent from vaccinal infection were used. The hair was removed with an electric clipper just before they were inoculated.

*Housing of Animals*—The rabbits under experiment were kept in individual cages, liberally supplied with food and water. For the experiments on the effect of high external temperature they were placed in a well ventilated room, the temperature of which was thermostatically controlled to within  $\pm 0.5^{\circ}\text{C}$ . It was soon learned that few animals survived transfer from the general animal quarters to a room heated to  $38^{\circ}\text{C}$  or more. However, if the temperature was gradually elevated, temperatures higher than this were tolerated with little obvious discomfort. Strict precautions were taken to prevent transmission of infectious material from diseased to normal animals, and during the course of these experiments no cross infections were observed.

*Protection Tests*—Tests for the presence of protective antibodies in the serum of recovered animals were made as follows. Serial tenfold dilutions of viral suspension were prepared covering the entire expected range of infectivity of the virus. To one portion of each dilution of viral suspension an equal amount of normal serum, and to another portion of the same suspension immune serum, was added and mixture was accomplished. Four inoculations of each mixture were then made intradermally into a single rabbit and the presence or absence of resulting lesions was recorded. Thus, two titrations of virus were accomplished, one in the presence of normal, and the other in the presence of immune, serum. The titers were calculated as before estimating from the data the dilution of virus which would give rise to lesions in 50 per cent of cases if multiple inoculations were practiced. It was assumed that the difference between the two titers represented the quantity of virus "neutralized," or against which protection was afforded.

*Precipitin Tests*—Precipitin tests were done according to the technique of Rivers and Ward (2). Antigen was secured by extracting the minced tissue secured from the skin of an animal heavily infected with myxoma. Incubation was at  $56^{\circ}\text{C}$  overnight.

Since the prime object of the study was to observe the effect of high environmental temperature on the course of infectious myxomatosis, the experiments were designed first to give this information.

Several groups of rabbits, after being acclimated to the desired temperature, were subjected to intradermal inoculation with serial tenfold dilutions (in amounts of 0.1 cc) of a suspension of active virus. At least three inoculations were made of each dilution, and a wide range (from undiluted stock suspension to a dilution of  $10^{-7}$ ) of dilutions was covered. Finally one or more animals was inoculated with the same viral dilutions and returned to the general animal quarters to serve as control. The animals were observed daily and records made as to the presence or absence of lesions at the site of inoculation, and as to the general character and approximate size of those present. The apparent titer of virus was recorded as the dilution giving rise to 50 per cent of positive results on inoculation, calculated according to the method of Muench and Reed (3). Animals alive at least 1 month after inoculation with lesions regressing were considered to have survived the infection.

The results of these experiments are presented in part in Fig. 1. There are represented the differences between the titer of the virus as recorded in the

control animals, and the apparent titer in the animals exposed to varying temperatures, in each case the points are plotted above the mean temperature prevailing during the experiment. It is apparent from the figure that the action of external temperature was a regular and very marked one. At the lowest temperatures used, no evident difference existed between the control and experimental animals as far as viral titer is concerned. At intermediate temperatures, there is manifest a wide variation in the response of individual rabbits to viral inoculation, the difference in apparent titer of virus being far greater than any which could possibly be accounted for on the basis of chance.

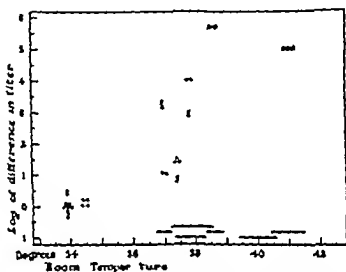


FIG. 1 Effect of environmental temperature on infection with myxomatosis. Each circle represents the result obtained with a single animal. The titer of virus in the control was taken as base, and the titer in experimentally treated animals compared with it. A diminished titer of virus in the experimental as compared with the control animal is plotted as a positive, and increased titer as a negative logarithm ( $\text{Log control titer} - \text{log experimental titer} = \text{log difference}$ .) The open circles indicate that no lesions appeared in the experimental animals and the titer of virus in them was accordingly taken to be 0.

Finally at the highest temperatures, no lesions at all followed insertion of even large amounts of active virus.

A detailed account of the events in two of these animals may be of importance. Rabbits 3-74 and 3-77 were inoculated with a series of dilutions of potent virus, at a time when the mean room temperature was  $41.0^{\circ}\text{C}$ . No lesions developed in 17 days of observation after which the room temperature was lowered. 5 days after the temperature had fallen to  $36.5^{\circ}\text{C}$  several large myxomatous lesions were found to have appeared. At this time, the temperature was raised again and these animals proceeded eventually to recover. It would appear that the virus of myxoma had persisted in them during the period of exposure to high temperature, without causing disease, but it became active again when more favorable conditions presented.

Another notable observation was that the difference in concentrations of the

suspension just giving all positive results on inoculation and that giving all negative results was approximately constant from rabbit to rabbit, including the control animals, even though there was considerable variation in apparent titer between different animals

The data of a representative experiment are presented in Table I. Because of the wide range of dilutions which had to be used in each rabbit, the number of inoculations per dilution was necessarily limited. Within the limits of the data, it is apparent that 100-fold dilution of a suspension which was just capable of causing lesions to appear regularly in a given rabbit, produced a suspension which gave no lesions *in that rabbit*, although the diluted suspension might still be highly infectious for another animal. This wide variation in the reactivity of different rabbits, but uniform response of the single animal was consistent during the entire study. Early attempts to apply

TABLE I

*Results of 7 Simultaneous Titrations of Virus*

The animals were kept at a temperature of 37.2-38.5°C. Control titer at room temperature  $10^{-4.5}$ . The numerator indicates the number of lesions appearing, the denominator the number of inoculations at indicated dilution.

Viral dilution	Rabbit No						
	1-94	1-97	4-06	4-07	4-08	4-15	4-20
$10^{-1}$	4/4	4/4	4/4	4/4	4/4	4/4	4/4
$10^{-2}$	4/4	4/4	4/4	4/4	4/4	4/4	4/4
$10^{-3}$	4/4	4/4	4/4	4/4	0/4	4/4	0/4
$10^{-4}$	4/4	4/4	1/4	0/4	0/4	3/4	0/4
$10^{-5}$	4/4	4/4	0/4	0/4	0/4	2/4	0/4
$10^{-6}$	0/4	1/4	0/4	0/4	0/4	0/4	0/4
50 per cent dilution	5/50	5/66	3/66	3/50	2/50	4/68	2/50

statistical methods of analysis of the data obtained after pooling the results obtained from several animals had to be abandoned, as it was obvious that the host factor was the determining one in the combined data. Nevertheless, the titration curve for any individual animal did not seem to differ from the titration curve of virus in the control animal, although conditions precluded the securing of conclusive evidence (4).

In addition to the effect on the apparent titer of virus, elevation of external temperature produced other profound modifications in the infection, most dramatic of which was in the mortality rate. Data are presented in Table II on the mortality of animals in relation to the difference in apparent titer between control and experimental rabbits. It is seen that at low temperatures, little difference existed between viral titer in control and experimental animals, and that but one animal survived. It happened that this animal did not receive inoculations of the more concentrated suspensions, and only a few

lesions developed. Whether or not survival in this instance can certainly be attributed to the slight elevation of temperature may be debated, although it has been the experience of others that infection initiated with minimal amounts of virus is regularly fatal. At the higher temperatures, however, there seems to be a definite correlation between the temperature and recovery rate, for when the room temperature was above 36°C 23 of 28 animals inoculated survived the infection. That the whole course of the infection was actually being altered was apparent also from the daily inspection of the animals. In rabbits with myxomatosis under normal conditions, the disease is a progressive one. Lesions appear at the sites of viral inoculation more or less promptly depending upon the concentration of virus inserted. These enlarge progressively, and if of considerable size show a markedly congested central area, which may break down, exhibiting the typically myxomatous

TABLE II  
*Effect of Environmental Temperature on Mortality from Myxoma*

Log of difference in titer	Temperature			
	33-36°C.		36-42°C.	
	T*	S	T	S
1 -0.1	3	1		
0 -1	7	0	7	4
1 1-2			4	2
2 1-6			17	17
Total	10	1	28	23

\* T = total number S = number surviving in indicated groups.

character of the swelling. By the end of a week, generalization of infection has almost invariably occurred, with lesions widespread in the skin, on mucous membranes, and particularly at mucocutaneous junctions. No regression of the individual swellings is observed. In the animals benefiting from exposure to high temperature, the course is much different. The lesions as they develop in the first few days much resemble those in the control. They progress more slowly, however, there is less erythema, and by the 6th to 8th day their development is maximal. At about this time the central portion becomes cyanotic, and within the next day or so there is apparent a slight regression of the swelling at the edges of the mass, often giving this a broadly pedunculated character. Secondary lesions when they appear tend to be few, and hardly ever attain any considerable size, the largest rarely having a diameter of 10 mm. As time progresses the lesions heal, those of any considerable size healing after the separation of a central slough of necrotic tissue. Within 3

weeks as a rule, the animal has completely recovered, save perhaps for the healing of some of the larger ulcers

The state of immunity of the experimental animals on recovery is of considerable interest, and certain observations of it have been made. While all tests were not applied to all animals, sufficient data are available to give a reasonably complete picture

TABLE III  
*Tests of Immunity of Rabbits Surviving Myxoma*

Rabbit No	Apparent titer of virus (log)	Secondary lesions	Room temperature	Tests of serum		Results of reinoculation		
				Precipitin	Protection	Titer of virus	Secondary lesions	Died Survived
			°C					
4-89	2.4	—	39.4-40.6	1-2*		6.0	+	S
4-45	0.5	—	" "	Negative		6.0	+	D
3-43	5.5	—	36.7-37.2	1-32	Pooled†	NR‡	—	S
3-46	6.0	—	" "	1-32	"	"	—	"
3-88	5.0	—	" "	1-32	"	"	—	"
3-89	3.0	—	" "	1-32	"	"	—	"
3-95	5.5	—	" "	1-2	"	"	—	"
3-74		+	40.4-41.5	1-2		"	—	"
3-77		+	" "	1-8		"	—	"
4-06	3.7	—	37.2-38.5	1-4	0			
4-07	3.5	+	" "	1-2	0			
4-08	2.5	+	" "	1-2	0	5.7	+	D
4-15	5.3	+	" "	1-8	0		+	"
4-20	2.5	—	" "	Negative	0			
4-04	3.0	—	" "	1-16				

\* Highest dilution of serum giving visible precipitate

† Sera not tested individually but as a pool, this protected against  $10^{4.7}$  infectious units

‡ No response to lowest dilution of viral suspension inoculated

|| No lesions on first inoculation, lesions appeared later, see text

Some time in early convalescence, after removal to the general animal quarters, the animals were bled and the serum separated. This was kept for tests of antibody content, and the rabbit was meanwhile subjected to reinoculation with active virus

In Table III are collected the data on titer of precipitins and protective antibodies, and the results of reinoculation. It would not appear wise to draw final conclusions from the amount of information available, yet certain tentative deductions seem to be in order. Thus, there does not seem to be a perfect correlation between the apparent severity of the initial disease, and the response to reinoculation. Rabbit 4-45, having passed through a mild disease, developed no precipitating antibodies and died of myxomatosis on reexposure



On the other hand, the same outcome followed the reexposure to virus of rabbit 4-08, in which the original infection had seemed much more severe. No protective antibodies were found in the serum of this rabbit, nevertheless, and fatal myxomatosis followed reinoculation. Of 4 animals convalescent from generalized infection, 2 succumbed on reinoculation, while of 7 with no evident secondary lesions, 5 recovered. It was regularly observed that those rabbits which showed any evident signs of infection when reinoculated with virus developed lesions after inoculation of minimal amounts of it, and all showed many secondary lesions during the course of this second infection, although 1 recovered. Those animals which were evidently resistant to the virus showed no signs of actual infection when reinjected. All of these animals did respond to the reintroduction of virus with a very marked allergic reaction, the more concentrated viral suspensions causing the appearance of large areas of edema (3 x 5 cm. in diameter) which developed rapidly and had as a rule subsided completely with 72 hours of the inoculation. That the allergic reaction itself was not the actually protective mechanism was evident from the fact that in some animals as it subsided the signs of infection appeared, and fatal myxomatosis followed.

#### SUMMARY AND CONCLUSIONS

Rabbits, convalescent from vaccinia and in good general health, were subjected to infection with myxoma during a period of exposure to a high external temperature. It was observed that in proportion as the temperature was elevated, a profound change in the course of the myxoma infection occurred. At the highest temperatures, the disease was held completely in abeyance, and no lesions appeared within 17 days of observation. At lower temperatures, lesions appeared which tended to be circumscribed, and which reached their maximum development within 6 or 8 days after inoculation. Regression then set in and complete healing occurred. There was wide variation in the degree of protection which a given temperature conferred on an individual rabbit as measured by the amount of virus required to cause infection, although for single animals the difference in concentration of virus required to produce consistently positive and consistently negative results was not apparently different from that obtaining in the controls. With the data at hand, it does not appear justifiable to draw final conclusions as to the state of immunity of the animals which survived the modified infection.

#### BIBLIOGRAPHY

- 1 Thompson, R. L., *J Infect Dis* 1938 62, 307
- 2 RIVERS, T. M., and WARD, S. M., *J Exp Med* 1937, 66, 1
- 3 Muench, H. and Reed L. J., *Am J Hyg*, 1938, 27, 493
- 4 Parker, R. F., Bronson, L. H., and Green, R. H., *J Exp Med*, 1941, 74, 263



# COMPARATIVE STUDY OF MENINGOPNEUMONITIS VIRUS, PSITTACOSIS OF PIGEON ORIGIN, AND PSITTACOSIS OF PARROT ORIGIN

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In a previous paper (1), the recovery of a virus morphologically identical with psittacosis from pigeons on a thiamin-deficient diet was reported. This virus, injected intracranially into mice behaved like typical psittacosis, producing fatal meningoencephalitis with typical elementary bodies. The virus differed from typical psittacosis, however, in that intraperitoneal injection in mice failed to produce apparent illness. Cross immunity tests with typical psittacosis were not carried out. The conclusion was drawn largely on morphological grounds that the virus was closely related to, if not identical with that of psittacosis.

Francis and Magill (2), in 1938, described a virus recovered from ferrets inoculated with throat washings from human cases of an influenza like respiratory infection. It was not clear whether this virus was derived from the inoculated human material or from the ferrets. In mice, it produced fatal meningitis after intracranial injection, and fatal pneumonitis after intranasal injection. After intraperitoneal inoculation, a fatal meningitis was produced in some mice. The hepatic necroses characteristic of psittacosis were not found. They were unable to identify their virus, and gave it a descriptive name—the virus of meningopneumonitis.

Eaton, Beck, and Pearson (3) have recently reported the recovery of a virus from four cases of human atypical pneumonia by intranasal injection into mice. This virus, in its properties, was practically identical with the virus of Francis and Magill. It showed immunological relationship but incomplete immunological identity with the latter virus and also with psittacosis. It produced a fatal illness in mice, transmissible by intracranial or intranasal inoculation, but like our pigeon virus, was apparently non virulent in mice when injected intraperitoneally.

The experiments to be reported here were designed to test the hypothesis that these viruses might be related to the virus recovered from pigeons.

## *Material and Methods*

Fully virulent typical psittacosis virus was kindly furnished by Dr. Karl F. Meyer. The meningopneumonitis virus of Francis and Magill was obtained by the courtesy of Dr. Eaton. Our virus of pigeon origin had been lost but records of its behavior

in experimental animals and microscopic slides showing its morphological characteristics were available. Comparative studies in pigeons and mice, of the behavior and morphology of (1) typical psittacosis, (2) the meningopneumonitis virus, and (3) our pigeon virus, were carried out

#### EXPERIMENTAL

Seven pigeons were injected intracranially with 0.06 cc each of brain emulsion from two mice dying of typical psittacosis, three pigeons from the emulsion of one brain and four from the emulsion of the other. Six mice were injected intracranially with 0.03 cc of each brain emulsion. The brain emulsified for injection into the group of four pigeons was proven by smears and sections to contain the characteristic elementary bodies of psittacosis in large numbers.

Nine pigeons were injected intracranially with 0.06 cc. each of tissue emulsions containing the meningopneumonitis virus. Twenty-two mice were injected intracranially with 0.03 cc. of these same emulsions.

Film preparations and paraffin sections were prepared from the brains of one or more animals of each group dying from the infections. The films were fixed in absolute methyl alcohol and stained by the Giemsa method. The tissues were fixed in Regaud's fluid and sections were stained by the Giemsa method.

#### RESULTS

The seven pigeons injected intracranially with typical psittacosis virus continued to eat well, held their heads up normally, and showed no evidence of illness during an observation period of 30 days. At the end of this period, they were killed. Autopsies showed no gross lesions, and microscopic sections of the brain and liver from two of them were entirely negative. Brain from one of these pigeons was emulsified and injected intracranially into six mice. These mice showed no evidence of illness. All mice injected intracranially with typical psittacosis virus died between the 3rd and 6th days after injection. Intracellular clusters of typical elementary bodies were found in large numbers in the brains of several of these mice.

The nine pigeons receiving intracranial injections of the meningopneumonitis virus of Francis and Magill all became ill on the 3rd or 4th days after injection. Failure to eat, ruffling of the feathers, and retraction of the neck were followed in a few days by inability to stand, staggering, or opisthotonos. Two pigeons died on the 7th day after inoculation. Three pigeons were killed in a moribund state between the 8th and 10th days after injection. The other four pigeons all suffered prolonged illness of variable severity. All mice injected with the meningopneumonitis virus died (with one exception) between the 3rd and 6th days after injection, with evidence of paralysis.

Sections of the brain of four pigeons dying of the disease or killed when moribund showed meningitis and encephalitis. In both smears and sections, many intracellular clusters of elementary bodies, giving the picture characteristic of infection with the psittacosis virus, were found. Sections of brain

from several mice injected with the virus showed a similar histological picture and entirely similar clusters of elementary bodies. Histologically, the meningoencephalitis produced in pigeons and mice with the meningopneumonitis virus showed a picture identical with that seen in pigeons and mice after intracranial inoculation of our virus of pigeon origin. The meningoencephalitis produced in mice was also indistinguishable histologically from that produced by the intracranial injection of typical psittacosis virus. A careful comparison of the intracellular clusters of elementary bodies found in typical psittacosis, in meningopneumonitis, and in our pigeon virus, showed apparently complete identity (These structures are often called L.C.L. bodies)

TABLE I

*Comparative Pathogenicity of Psittacosis Viruses for Pigeons by the Intracerebral Route*

Origin	No. of pigeons	Results
Pigeon (1)	2	2 died, 3rd day L.C.L. bodies.
Pigeon (7754)	2	2 died, 3rd and 10th days, paralysed.
Pigeon (Haines)	2	2 died 3rd and 15th days paralysed.
Pigeon (Pas. 1868)	3	3 died, 3rd to 15th days paralysed.
Pigeon (Ylaskia 59)	2	2 died, 4th and 7th days, paralysed.
Pigeon (Br lung)	4	2 died, 6th and 12th days, paralysed.
Parrot (King 1939)	2	No illness. Killed 51st day
Parrot (dwarf 1938)	2	No illness. Killed 51st day
Parakeet (2 Al)	4	1 died, 64th day 3 killed 142nd day
Parakeet (6 BG)	6	1 died, 14th day 3 killed, 37th to 55th days.
Parrot (Cohn M)	4	2 died 5th and 6th days. 2 killed, 47th and 123rd days.
Parakeet (human lung, 1940)	6	No illness. Killed 102nd to 104th days.
Parrot (human sputum 1941)	2	1 died, 7th day 1 paralysed recovered.
Parrot (human sputum 1940)	2	No illness. Killed 29th day
Parrot (human sputum, 1940)	3	No illness. Killed 29th day

Dr Karl F Meyer kindly offered to test in greater detail the comparative pathogenicity of several strains of psittacosis virus of pigeon and of parrot origin when injected intracerebrally in pigeons. The results of this study are shown in Table I. Sixteen of the eighteen pigeons injected with viruses of pigeon origin died between the 3rd and 15th days, while only three early deaths, one late death, and one illness with recovery were noted among thirty-one pigeons injected with virus of parrot origin. In this group, the morbidity and mortality was confined to pigeons injected with recently isolated strains, while the meningopneumonitis virus had been carried in mice for several years. On the whole, therefore, the results which Dr Meyer obtained confirm the belief that psittacosis viruses of pigeon origin show a significantly greater pathogenicity for pigeons when injected intracerebrally.

Certain other observations made by Dr Meyer in the course of his studies should also be recorded. Contrary to our negative results obtained from one pigeon, Dr Meyer on several occasions recovered virus from the organs of pigeons which showed no illness after the intracranial injection of strains of parrot origin, in one instance, as late as the 123rd day after injection. Complement fixation tests for psittacosis were also regularly positive in such clinically negative birds. These observations indicate that even when no apparent illness occurs, latent infection is commonly produced in pigeons by the injection of virus of parrot origin.

Another observation of interest was that two pigeons, even though proven to have latent infection by positive complement fixation tests, died of psittacosis on the 4th and 7th days after the intracranial injection of virus of pigeon origin.

#### DISCUSSION

The detailed morphological picture of cells containing clusters of L.C.L. bodies is believed to be unique, although the elementary bodies of lymphogranuloma venereum resemble them closely under certain conditions. The presence of this picture in pigeons and mice infected with the meningopneumonitis virus and with our pigeon virus is believed to be strong presumptive evidence that both of these viruses are strains of psittacosis. Close immunological relationship between the meningopneumonitis virus and typical psittacosis further supports this point of view, even though complete immunological identity does not obtain. Eaton, Beck, and Pearson (3) have found that solid immunity, even against homologous strains of virus in animals inoculated by the intranasal or intracerebral routes, is rather uncertain.

The similarities and differences between the four viruses under consideration are brought out in Table II. The ability to produce serious and usually fatal infection in pigeons with regularity after intracranial injection is shared by the meningopneumonitis virus and our pigeon virus<sup>1</sup> while typical, fully virulent psittacosis failed to produce evidence of illness in pigeons, except in a few instances when recently isolated strains were tested. The meningopneumonitis virus and our pigeon virus seem to have in common also a tendency toward "neurotropism." It has not been shown that these two viruses are identical, but their biological departure from typical psittacosis appears to be in the same direction in both cases.

The differences demonstrated between these viruses and typical psittacosis virus are apparently similar to, although quantitatively somewhat greater than, those which obtain between human and murine typhus. Such modifications,

<sup>1</sup> Four out of six pigeons injected intracranially with our pigeon virus died with meningoencephalitis and associated L.C.L. bodies. The other two became ill but recovered (previously unpublished observations).

which are of a rather permanent nature, are presumably due to prolonged residence in different species of animals, but are commonly believed to be reversible under suitable conditions.

Dr Meyer, has seen several instances of proven psittacosis in man without contact with psittacine birds but with contact with doves and pigeons. Serologically, the existence of latent psittacosis infection was proven in seven out of nineteen doves and in a number of pigeons. It has not been demonstrated that human psittacosis acquired from pigeons shows any distinctive clinical features as compared with cases of parrot origin.

TABLE II  
*Comparison of Behavior and Morphology of Four Viruses*

	Pigeons intracranial	Mice intracranial	Mice intraperitoneal
Typical psittacosis	Usually negative	Fatal meningoencephalitis. L.C.L. bodies*	Fatal with hepatic necrosis. L.C.L. bodies.* Brain negative (4)†
Atypical psittacosis from pigeons (Pinkerton and Swank)	Fatal meningoencephalitis. L.C.L. bodies*	Fatal meningoencephalitis. L.C.L. bodies*	Negative
Meningopneumonitis virus (Francis and Magill)	Fatal meningoencephalitis. L.C.L. bodies*	Fatal meningoencephalitis. L.C.L. bodies*	Occasional fatal meningoencephalitis (2).† No hepatic necrosis.
Atypical pneumonia virus (Eaton, Beck, and Pearson)	Not tested	Fatal meningoencephalitis (3)†	Negative (3)†

\* Intracellular clusters of coccoid elementary bodies of variable size, giving the unique and characteristic morphological picture of infection with the psittacosis virus.

† Observations not made by us, but taken from reports of other workers. Figures indicate references.

It has recently been suggested (5-7) that the virus of lymphogranuloma venereum may be closely related to psittacosis and to the virus of meningopneumonitis, since these viruses all have antigenic components in common, all produce meningitis, pneumonia, and granulomatous cutaneous lesions, and are all associated with the presence of elementary bodies in infected tissues. Our observations have shown complete morphological identity between the virus of typical psittacosis, the atypical "psittacosis" virus of pigeon origin, and the virus of meningopneumonitis, and for this reason we regard these viruses as closely related.

The morphological picture of lymphogranuloma venereum, as seen in smears and sections of the mouse brain, seemed to us to differ rather strikingly from that of psittacosis. The clusters of elementary bodies in the former appeared less compact, and the larger coccoid bodies, often appearing in mulberry form, which are a characteristic feature of psittacosis were not found in lymphogranuloma venereum. Rake and Jones (8), however, report that in the yolk sac of the developing chick embryo the larger forms are seen, and these workers stress the marked morphological similarity of lymphogranuloma venereum and psittacosis, under the conditions of their studies. The exact relationship of lymphogranuloma venereum to psittacosis requires further study.

#### SUMMARY

Comparative morphological, histological, and biological studies suggest a close relationship between the meningopneumonitis virus of Francis and Magill and a virus recovered from thiamin-deficient pigeons. Both of these viruses are morphologically identical with typical psittacosis, and it seems probable that they are biologically modified strains of psittacosis. They both differ from typical psittacosis in that they are regularly more pathogenic for the pigeon after intracranial injection, and fail to produce hepatic necrosis after intraperitoneal injection in mice. A virus recently isolated from human cases of atypical pneumonia by Eaton, Beck, and Pearson may also be closely related to these two viruses.

A number of psittacosis viruses of pigeon origin showed a similarly increased pathogenicity for pigeons by the intracerebral route, as compared with psittacosis viruses of parrot origin. The viruses of parrot origin, however, commonly produced latent infection in pigeons even when clinical illness was not evidenced.

For the isolation of psittacosis of pigeon origin from human sputum the intracranial injection of mice or pigeons may be essential, although it is probable that the intranasal injection of mice would be successful. The intraperitoneal injection of mice may give negative results.

The authors acknowledge with pleasure the generous cooperation of Dr. Karl F. Meyer, who carried out the detailed comparative study of several psittacosis viruses of pigeon and parrot origin.

#### BIBLIOGRAPHY

1. Pinkerton, H., and Swank, R. L., *Proc Soc Exp Biol and Med*, 1940, 45, 704.
2. Francis, T., and Magill, T. P., *J Exp Med*, 1938, 68, 147.
3. Eaton, M. D., Beck, M. D., and Pearson, H. E., *J Exp Med*, 1941, 73, 641.
4. Rivers, T. M., and Berry, M. D., *J Exp Med*, 1931, 54, 105.
5. Shaffer, M. F., Rahe, G., and McKee, C. M., *Proc Soc Exp Biol and Med*, 1940, 44, 408.
6. Grace, A. W., and Suskind, F. H., *Am J Path*, 1940, 16, 169.
7. Eaton, M. D., Martin, W. P., and Beck, M. D., *J Exp Med*, 1942, 75, 21.
8. Rake, G., and Jones, H. P., *J Exp Med*, 1942, 75, 323.



# LYMPHOCYTIC CHORIOMENINGITIS IN THE SYRIAN HAMSTER

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The Syrian hamster (*Cricetus auratus*) has been shown to be highly susceptible to St. Louis (1, 2) and to Japanese (2) encephalitis. Since this animal is now readily available in the United States for laboratory work, it seemed desirable to test its response to other infectious agents. Our own preliminary observations, like those of Kreis (3), indicated that the virus of lymphocytic choriomeningitis could be recovered from inoculated Syrian hamsters although it caused no apparent clinical disease in them. The intense but silent infection which was subsequently found to occur under these conditions provided an opportunity to study the immunological and pathological response of an apparently healthy host that carried large amounts of virus. The importance of this type of silent infection as a reservoir for the spread of diseases as diverse as lymphocytic choriomeningitis (4, 5), yellow fever (6), psittacosis (7), rabies (8), pseudorabies (9), Russian encephalitis (10), Q fever (11, 12), and sylvatic plague (13) has been pointed out by workers in these fields and discussed by Andrewes (14) and by Meyer (15). The inapparent infection of hamsters with the virus of choriomeningitis should be of interest to laboratory workers because of the possibility that this agent might be carried as a contaminant during the passage of other neurotropic viruses. The present communication reports the results of work dealing with the distribution and persistence of virus in hamsters, and with the serological response of this host to infection. In addition, observations are presented concerning the simultaneous infection of the hamster with a mixture of the viruses of lymphocytic choriomeningitis and St. Louis encephalitis.

## Materials and Methods

**Hamsters**—Young adult Syrian or golden hamsters (*Cricetus auratus*) were employed. The animals bred at The Rockefeller Institute were kept under strict isolation until they were 4 to 6 months old at which time they weighed 100 to 150 gm each.

**Virus**—Brain tissue of a guinea pig infected with the 92nd guinea pig passage of the W.E. (16) strain of choriomeningitis virus was used to initiate infection in hamsters. The Hubbard strain of St. Louis encephalitis virus, isolated in 1937 (17), was employed, this agent had been through 92 serial passages in mice and then 6 passages in Syrian hamsters when given to us by Dr. E. H. Lennette, virus from the 14th passage in hamsters was used.

**Antisera**—3 cc. of blood to be tested were obtained by intracardiac puncture from

hamsters held under ether anesthesia. As a rule, the animals were fed only lettuce for a day or so before bleeding in order to lessen the anticomplementary activity of their serum. Specimens of serum, which were often lipemic, were partially clarified by centrifugation at 12,000 R.P.M. for 20 minutes in the cold.

*Serological Tests*—The techniques for the complement-fixation (18, 19) and neutralization (19) tests have already been described in detail. The chief features of the former test were the use of 2 units of complement, 2 units of amboceptor, a 5 per cent suspension of washed sheep erythrocytes, and fixation overnight at 3°C. Standard solutions of soluble antigen prepared from infected guinea pig spleens and hyperimmune guinea pig serum were used in the initial tests with hamster immune serum and with extracts of hamster tissue, respectively. The tests were controlled with serum and tissue extracts from normal hamsters. Subsequently, antigen and antibody obtained from hamsters were standardized and employed for the work with hamster material. The neutralization test was carried out in guinea pigs, 4 animals were inoculated subcutaneously with a mixture of the test serum and a virus suspension diluted so that it contained approximately 1000 M.L.D.

*Titration of Virus*—Suspensions of material to be tested for virus activity were inoculated intracerebrally into anesthetized Swiss mice. Serial tenfold dilutions of the material were tested, and 0.03 cc. of each dilution were injected into each of 3 mice. The titration end point was regarded as that dilution which killed at least 2 of the 3 mice in a group within 14 days, when the remaining mice were discarded. 10 per cent suspensions of blood and of organs were made on the basis of volume and weight, respectively. Physiological saline solution, pH 7.2, containing 2 per cent normal inactivated guinea pig serum, was used as diluent throughout the titration.

#### EXPERIMENTAL

##### *Infection of Hamsters with the Virus of Choriomeningitis*

Intracerebral or intraperitoneal inoculation of choriomeningitis virus into hamsters resulted uniformly in the appearance of large amounts of the active agent in their blood and organs as early as the 5th day. Furthermore, the agent was regularly detectable in high concentration throughout the body during the 2nd and 3rd weeks after inoculation, and in a few instances it was demonstrable in the brain as late as the 6th and 8th week. The results of a series of titrations in mice of blood, brain, and spleen taken from hamsters at various intervals after inoculation of virus are summarized in Table I. It is apparent from the data presented that during the first 3 weeks of the disease the titer of the blood ranged between  $10^3$  and  $10^5$  lethal doses and that the titers of brain and spleen were as high as  $10^6$  and  $10^8$ , respectively. Additional observations indicate that the liver and lung contained virus in amounts comparable to that found in the blood. Similarly, intratesticular inoculation resulted in a generalized infection, at the end of the 1st week the titer of the testicle was usually lower than that of the spleen from the same animal, e.g.,  $10^4$  lethal doses in the testicle and  $10^6$  in the spleen. The virus was passed in hamsters through 5 serial transfers from brain to brain at 5 to 7 day intervals,

since it apparently could be carried indefinitely in this host, further passage was not attempted.

Almost all of the hamsters appeared well following inoculation of virus. Among a total of 54 hamsters infected with choriomeningitis virus during the

TABLE I

*Distribution and Persistence of Virus in Hamsters and Their Antibody Response to Infection with Lymphocytic Choriomeningitis*

Hamster*	Time after inoculation	Appearance	Titer of virus			Antibody tests	
			Blood	Brain	Spleen	Complement-fixing	Neutralizing
1 1	5 days	Well	$10^{-4}$	$10^{-4}$	$10^{-4} \dagger$	Not done	Not done
1-6	5 "	"	$10^{-3}$	$10^{-3}$	$10^{-4} \dagger$	"	"
5-10	7 "	"	$10^{-3}$	$10^{-4}$	$10^{-4} \dagger$	—	"
5-2 3	11	"	Not done	Not done	Not done	1 32	"
5-13, 14	14 "	"	$10^{-4}$	$10^{-3}$	$10^{-3} \dagger$	1 16	"
5-12, 15	21 "	"	$10^{-3}$	$10^{-3}$	$10^{-3} \dagger$	1 32	"
1 15	22 "	Moribund $\ddagger$	Not done	$10^{-3}$	$10^{-4}$	Not done	"
5-17	28	Well	—	—	—	1 32	—
1 12	28	Moribund $\ddagger$	Not done	$10^{-4}$	$10^{-4}$	Not done	Not done
2 2 3	32	Well	—	Not done	Not done	1 128	—
1 19	35 "	"	$10^{-1}$	$10^{-1}$	"	Not done	—
5-18	35	"	—	$10^{-3}$	—	1 128	Not done
1 20	35 "	"	—	—	—	Not done	—
5-19	42 "	"	—	—	—	1 16	Not done
1 2A	42 "	"	—	$10^{-3}$	Not done	1 64	+
5-20	49 "	"	—	—	—	1 32	Not done
2 2	53 "	"	Not done	Not done	Not done	1 64	+
1 3	56	"	—	$10^{-3}$	"	Not done	+
1 17	84	"	—	—	— $\S$	1 32	Not done
Pool 2	8 mos.	"	Not done	Not done	Not done	1 32	+

Blood and organs were considered to be non-infectious when mice injected with a  $10^{-1}$  dilution of them remained well; more concentrated suspensions were not tested.

\* First number indicates passage; second number indicates animal in passage.

$\dagger$  Complement fixing antigen demonstrable.

$\S$  not demonstrable

$\ddagger$  Cross-immunity tests indicated presence of choriomeningitis virus.

course of this work, only 3 became obviously ill, data on 2 of these animals are recorded in Table I. The clinical signs displayed consisted of weakness, conjunctivitis, loss of weight, dehydration, occasionally tremors and, finally, prostration, however, in no instance did the signs develop until 3 to 4 weeks after inoculation. All of the animals in this group of ill hamsters had demonstrable virus in their tissues but only one, 1 15, was free from an obvious bacterial infection, the remaining 2 had an infection caused by an organism

closely related to *Klebsiella capsulata*<sup>1</sup> While it cannot be said that hamsters never die as a result of infection with the virus of choriomeningitis, it is evident that such an occurrence is rare

Traub (22) has demonstrated that the urine of mice and of guinea pigs infected with the virus of choriomeningitis is infectious, and Armstrong (23) has stated that the feces of such mice likewise contain the virus Our preliminary experiments, in which attempts were made to demonstrate the virus of choriomeningitis in urine and feces of infected hamsters, gave irregular results when bacteriologically sterile materials were obtained and tested intracerebrally in mice The procedures employed to insure bacterial sterility apparently also reduced or destroyed the activity of the virus, consequently, the following experiment was performed

Urine and feces were collected from 2 hamsters on the 6th day after intracerebral and intraperitoneal inoculations with a suspension of brain from a hamster of the 4th passage Urine which was obtained by gentle compression of the bladder was collected without fecal contamination Several pellets of fecal material were removed from the rectum with small forceps, contamination by urine or by capillary hemorrhage was avoided The fecal material was emulsified in 5 cc of serum-saline solution and centrifuged 3 times at 2500 R.P.M. for 20 minutes, the opalescent supernatant fluid was transferred to a sterile test tube before the next centrifugation Urine was centrifuged only once Cultures of both of the final preparations subsequently revealed the presence of an appreciable number of bacteria Serial tenfold dilutions of each preparation were made and inoculated subcutaneously into normal guinea pigs, each of 2 animals received 0.5 cc of each dilution, i.e.,  $10^{-1}$  to  $10^{-4}$  All animals inoculated with the  $10^{-1}$  to the  $10^{-3}$  dilutions of urine and of feces died after exhibiting fever and the usual signs of choriomeningitis, furthermore, one of the animals which received the  $10^{-4}$  dilution of urine succumbed In order to establish conclusively the etiology of the disease in the guinea pigs, the virus of choriomeningitis was identified in three instances in the following manner

Blood and splenic tissue from 2 guinea pigs which died after receiving the  $10^{-1}$  and  $10^{-2}$  dilutions, respectively, of urine were bacteriologically sterile Spleens from both animals were shown to contain the specific soluble antigen of choriomeningitis when tested by complement fixation, and one of the spleens was found to be infectious

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<sup>1</sup> This organism (*Klebsiella capsulata*) apparently causes rather frequent infections in our hamster colony The most common lesion is a chronic, subcutaneous abscess which often breaks down, forming a draining sinus or a large indolent ulcer Ultimately death occurs following the development of septicemia, generalized lesions, and cachexia The most striking of these lesions are areas of acute focal necrosis in the liver which are visible macroscopically and peritonitis and pleurisy with a gelatinous exudate, which on direct bacterial examination shows many organisms with enormous capsules We hesitate to consider this infection an epizootic disease analogous to that caused in guinea pigs by Group C hemolytic streptococci (20, 21) because we think that the infection is generally initiated by biting

in a dilution of  $10^{-6}$  when titrated intracerebrally in mice. The spleen from 1 of the guinea pigs inoculated with a suspension of feces likewise possessed the soluble antigen of chorionmeningitis, in addition, bacteriologically sterile blood drawn from another sick animal on the 9th day after receiving fecal material produced a fatal infection when injected into 2 normal guinea pigs but caused no illness in 2 guinea pigs known to be immune to chorionmeningitis virus.

The results of the experiment indicate that the virus of lymphocytic chorionmeningitis appears in the urine and feces of infected hamsters in amounts comparable to that found in the blood.

Comparatively minor pathological changes were generally observed in hamsters affected by this silent virus infection. The only macroscopic abnormality regularly encountered was a moderate enlargement and congestion of the spleen. Microscopic examination of sections from various organs revealed few changes worthy of note. Histological sections prepared from brains which had been demonstrated by titration studies to contain virus in appreciable amounts generally showed only a mild meningeal reaction consisting of a few scattered lymphocytes in the subarachnoid space. This was true even of hamster, 1 15, which appeared moribund on the 22nd day. On the other hand, hamster, 1 12, which was moribund on the 28th day, was found to have an extensive meningo-encephalitis and pyelonephritis on histological examination. Bacteriological cultures of the brain and spleen of the latter animal were sterile, but those of the liver revealed a few colonies of *Klebsiella capsulata*. The lesions in the brain of this hamster consisted of collections of mononuclear cells about vessels in the meninges and brain tissue, and swelling and hyperplasia of cells of the choroid with scattered infiltrations of lymphocytes about the capillaries, destruction of nerve cells was not encountered.

*Failure to Obtain the Virus of Chorionmeningitis during Serial Passage of  
"Normal" Hamster Tissue*

Inasmuch as epizootics of lymphocytic chorionmeningitis (24) have been observed in laboratory stocks of white mice, monkeys, and guinea pigs, the question arose as to whether or not the virus occurred as a silent infection in our so called normal hamsters. During the course of the present work, experiments designed to test the susceptibility of hamsters to the virus of measles were carried out, evidence was obtained which indicated that the virus of chorionmeningitis was not present fortuitously in this host, as shown by the following experiments.

Blood and throat washings were obtained from 3 children within a few hours after the first appearance of a measles rash.<sup>2</sup> Four hamsters were inoculated intranasally,

<sup>2</sup> We wish to thank Dr. Jerome Cohn and Dr. Irving Klein for making available to us material from two of these children who were patients in the Willard Parker Hospital, New York. The third individual was a patient in The Rockefeller Hospital.

intracerebrally, and intraperitoneally with plasma from patient, E H, and 4 were injected intracerebrally, intranasally, and intraperitoneally with ether-treated throat washings. None of the animals developed evidence of disease except one of the hamsters that received plasma, it was ill on the 5th day and when sacrificed at that time was found to have pulmonary consolidation which yielded a heavy growth of *Klebsiella capsulata*. This organism induced a fatal, generalized infection in normal hamsters. A suspension of pooled brain and lung tissue obtained from one of the original hamsters on the 7th day following injection with the patient's plasma was bacteriologically sterile and was passed to normal hamsters. In this manner 4 serial transfers were made. None of the animals showed clinical signs of disease. Moreover, no significant lesions were observed in those which were sacrificed for passage. Serum taken from the hamsters 3 to 4 weeks after injection with human or with hamster-passaged materials did not contain complement-fixing antibodies for the soluble antigen of choriomeningitis, and, in addition, serum from several hamsters gave negative results for neutralizing antibodies of choriomeningitis. Materials from patients, L A and H G, were studied in a similar but less thorough manner. Eight hamsters were injected with plasma and throat washings from the former patient and a subsequent passage was made, while only 4 animals were inoculated with serum from the latter patient. All of the animals remained well and none of them developed antibodies specific for choriomeningitis.

Among the 34 hamsters from our normal stock employed in these experiments there was no evidence of an indigenous infection with the virus of lymphocytic choriomeningitis.

#### *Correlation of Virus, Soluble Antigen, and Antibodies in the Syrian Hamster*

Tissues of hamsters infected with the virus of choriomeningitis contain a specific soluble antigen which is serologically identical with that found in tissues of other animals affected by the disease (25). The antigen has been consistently demonstrable in complement-fixation titers of 1:8 to 1:32 in preparations of spleens taken from hamsters 5 to 8 days after injection of virus. It is no longer detectable, however, by the 14th day which is approximately the time when complement-fixing antibody makes its appearance in the circulating blood (see Table I). The complement-fixing antibody increases in amounts until about the 4th to 6th week, it then gradually declines but persists, in some instances, for at least 8 months.

It is apparent from the data presented in Table I that complement-fixing antibody is present in appreciable amounts at a time when virus is circulating in the blood. Moreover, the disappearance of circulating virus after the 3rd week seems to bear no direct relationship to the general increase at about this time of antisoluble substance antibody. For example, both blood and organs of hamsters, 5-12 and 5-15, which were sacrificed on the 21st day, contained  $10^3$  M.L.D. of virus and the complement-fixing titer of their pooled serum was 1:32, whereas hamster, 5-17, sacrificed on the 28th day, had no demonstrable

virus in its blood or organs and the complement fixing titer of its serum was also 1:32.

The data summarized in Table I indicate that the blood and splenic tissue frequently lose their infectivity by the 28th day, but occasionally small amounts of circulating virus may persist until the 35th day. In addition, the data show that neutralizing antibodies generally appear in the serum at about the 6th week. It may be pointed out that in 3 animals, which were sacrificed at 5, 6, and 8 weeks after inoculation, virus was demonstrable in the brain but not elsewhere. Moreover, 2 of these animals, 12A and 1-3, possessed neutralizing antibody in their blood at a time when active virus was obtained from their brains. In general, these observations indicate that resistance to infection becomes evident during the 4th week after inoculation when virus begins to disappear from the blood and most of the organs and at a time when neutralizing antibodies are not present in quantities sufficient to neutralize 1000 M.L.D. of virus, by the 6th week, however, such an amount of neutralizing substance has appeared in the serum of the majority of the animals.

#### *Simultaneous Infection of the Hamster with the Viruses of Lymphocytic Choriomeningitis and St. Louis Encephalitis*

The virus of choriomeningitis has inadvertently been carried along with other viruses during serial passage, e.g. with distemper virus transmitted in dogs (26) and with rabies virus grown in tissue cultures (27). Armstrong (28) has shown that a known mixture of the viruses of choriomeningitis and St. Louis encephalitis passed serially in monkeys results in the loss of the latter agent. On the other hand, when a similar mixture of the two agents is transmitted in mice, the virus of choriomeningitis is lost after a few passages while that of St. Louis encephalitis is maintained. Since the virus of choriomeningitis as a rule produces a generalized, non-lethal infection in the hamster at a time when infection with the virus of St. Louis encephalitis (1, 2) is causing death, it seemed likely that serial transmission of both agents might be accomplished simultaneously in this host. The results of an experiment designed to test this possibility are presented below.

A mixture containing equal parts of a 10 per cent suspension of guinea pig brain infected with the W.E. strain of the virus of choriomeningitis and a 10 per cent suspension of hamster brain infected with the Hubbard strain of the virus of St. Louis encephalitis was inoculated intracerebrally into 2 hamsters. The animals became moribund on the 4th day and were sacrificed. Their brains were removed and pooled, and a suspension of them was passed to normal hamsters. In such a way 5 successive passages were made. Organs from a hamster of the 5th passage (LCM + St.L. 5-1) which died on the 4th day after inoculation were tested for the presence of the two viruses in the following manner:

Suspensions prepared from brain, lung, and spleen were titrated in duplicate in

groups of normal mice and of mice immune to choriomeningitis, in addition, the suspension of brain tissue was titrated intracerebrally in normal guinea pigs. The choriomeningitis immune mice were approximately 7 weeks old when used and had survived intraperitoneal injections of 100 and 10,000 M.I.D. of active virus at the age of 3 and 6 weeks, respectively. A control group of the immune animals resisted  $10^5$  lethal intracerebral doses of the potent, WE guinea pig strain of virus. The results of the titration of tissues from hamster, 5-1, are summarized in Table II.

TABLE II

*Simultaneous Passage in Hamsters of the Viruses of Lymphocytic Choriomeningitis and St. Louis Encephalitis*

Inoculum from hamster, 5-1	Test animals	Dilution of intracerebral inoculum							
		$10^{-1}$	$10^{-2}$	$10^{-3}$	$10^{-4}$	$10^{-5}$	$10^{-6}$	$10^{-7}$	$10^{-8}$
Brain	Normal guinea pigs	2/2	2/2	2/2*†	2/2	2/2	2/2	2/2	0/2
	LCM immune mice	3/3	3/3	3/3	3/3	3/3	3/3§	2/3	
	Normal mice	3/3	3/3	3/3	3/3	3/3	3/3	2/3	
Lung	LCM immune mice	2/3	2/3	1/3					
	Normal mice	3/3	2/3	0/3	0/3	0/3	0/3	0/3	0/3
Spleen	LCM immune mice	0/3	0/3	0/3					
	Normal mice	3/3	3/3	1/3	0/3	0/3	0/3	0/3	0/3

Numerator represents number of animals which survived, denominator the number of animals inoculated.

\* A  $10^{-3}$  dilution of brain tissue of 1 of these guinea pigs when inoculated into 2 normal guinea pigs caused the death of both and when inoculated into 2 LCM immune guinea pigs produced no illness.

† Spleens from both these guinea pigs contained the specific soluble antigen of choriomeningitis.

§ A  $10^{-3}$  dilution of pooled brains from these mice killed 2 LCM immune hamsters but did not affect 2 St. Louis immune hamsters.

The data presented in Table II indicate that both viruses were present in large amounts in the brain of hamster (LCM + St L), 5-1. The titration end point of  $10^{-7}$  obtained in the normal and choriomeningitis immune mice warranted the assumption that encephalitis virus was present. This was conclusively proved by the intracerebral inoculation of a  $10^{-3}$  dilution of brain tissue from one of the moribund choriomeningitis immune titration mice into 2 hamsters immune to St. Louis encephalitis and into 2 hamsters immune to choriomeningitis. The former animals survived without obvious illness while the latter died on the 4th and 5th days after inoculation. Since guinea pigs



are highly susceptible to the virus of lymphocytic choriomeningitis (4, 16) and relatively insusceptible to the virus of St. Louis encephalitis (29), the results of the titration of the hamster brain (5-1) in this species suggested that the virus of choriomeningitis was present. Indeed, the presence of choriomeningitis in 2 of the guinea pigs employed in the titration was subsequently established by the demonstration of the presence of the soluble antigen of choriomeningitis in extracts prepared from their spleens (complement-fixing titer of each, 1:16), moreover, a  $10^{-3}$  dilution of brain tissue from one of the titration guinea pigs killed 2 normal guinea pigs but did not affect either of 2 choriomeningitis immune guinea pigs injected at the same time. Titration of partially consolidated lung tissue of hamster, 5-1, indicated that a small amount of encephalitis virus was present since the end points were similar in normal and in choriomeningitis immune mice. On the other hand, the spleen of this hamster apparently contained only the virus of choriomeningitis. Further identification of the agents in lung and spleen was not attempted. It thus appears that once the virus of St. Louis encephalitis has been contaminated with the virus of choriomeningitis, both agents can be transmitted serially in hamsters by the intracerebral route for at least 5 transfers. Furthermore, the clinical disease and the pathological lesions<sup>3</sup> produced by the mixed virus infection are indistinguishable from that produced by the virus of encephalitis alone.

#### DISCUSSION

The virus of lymphocytic choriomeningitis multiplies readily in the adult Syrian hamster, producing a systemic disease in which large amounts of virus are demonstrable in the blood, organs, urine, and feces. Infection in these animals is rarely accompanied by obvious signs of illness, furthermore, significant histopathological lesions are only occasionally encountered in their brains or elsewhere. Antibodies for the soluble antigen of choriomeningitis are demonstrable in the serum during the 2nd week, at a time when virus is still present in high titer in blood and organs. This observation provides further evidence for the opinion (19) that antisoluble substance antibodies possess little if any power to neutralize the virus. Although neutralizing antibodies are not detectable by our method until 6 weeks after inoculation, the earlier

<sup>3</sup> The pathological changes observed in brains of hamsters injected intracerebrally with the virus of St. Louis encephalitis are similar to those seen in infected mice (30). Meningeal infiltrations of mononuclear cells, particularly about vessels, are common, perivascular cuffs containing the same type of cells are found throughout the brain tissue, degeneration of nerve cells occurs here and there in all areas but is more frequent in Ammon's horn. Involvement of the choroid is not prominent in hamsters infected with the virus of encephalitis and it is not outstanding in those with choriomeningitis.

appearance of small amounts of these substances may account for the loss of infectivity of blood and most organs during the 4th week of the disease. The simultaneous presence of appreciable quantities of virus in the brain and of neutralizing antibody in the serum was demonstrated in 2 animals, one in the 6th and another in the 8th week. This observation suggests that the virus may parasitize certain cells for long periods of time without destroying them and without being itself destroyed by them. The inability of neutralizing antibody to penetrate intact cells and to inactivate virus situated intracellularly is well established (31).

Silent infection with the virus of choriomeningitis occurs in animals other than hamsters. For example, mice contaminated *in utero* present little evidence of disease, nevertheless, their blood, urine, and nasal secretions may be infectious for months (22). Moreover, certain strains of the agent produce in guinea pigs a systemic disease which is manifest clinically only by a slight rise in temperature of a few days' duration (25, 32). It should be pointed out that disease of a severity intermediate between the lethal type caused by the W E strain and the almost inapparent type caused by the W W S strain can be produced in guinea pigs by still other strains of virus (25). Therefore, silent infections with this virus appear to represent only one of a series of stages of severity. Thus, the response of dogs and ferrets (26) might be considered to belong on the scale close to the inapparent infections, because in these animals choriomeningitis virus multiplies sufficiently to be transmitted through at least several serial passages when distemper virus is carried concurrently. Finally, it is necessary to reconsider the group of animals (19) which have been regarded as resistant to the virus of choriomeningitis but which develop specific antibodies following inoculation of the virus. Can these antibodies be considered to develop entirely in response to a relatively small amount of virus which does not multiply? It seems unlikely that a single intraperitoneal injection of active virus would be sufficient to induce the formation of complement-fixing antibodies in rabbits (19) if no multiplication of virus had occurred. Although rabbits are considered resistant to choriomeningitis, the intracerebral inoculation of very young animals may be followed by retardation of growth and by the development of mild lesions in the choroid plexus and meninges (19). This at least suggests that some multiplication of virus occurs in rabbits and leads one to wonder whether or not a similar phenomenon occurs in other so called resistant animals which form specific antibodies.

#### SUMMARY

The virus of lymphocytic choriomeningitis produces an intense systemic infection in Syrian hamsters with few if any clinical and pathological signs of disease. Specific soluble antigen is demonstrable in the spleen of infected animals until about the 14th day when antisoluble substance antibodies make their appearance. Circulating virus disappears after the 4th week and neu-

tralizing antibodies are present in serum in detectable amounts shortly thereafter, both types of antibody persist for at least several months

The viruses of St Louis encephalitis and lymphocytic choriomeningitis can be concurrently passed in series in the brains of hamsters. The resultant disease is indistinguishable from that caused by the virus of St Louis encephalitis alone.

## BIBLIOGRAPHY

- 1 Broun, G O, Muether, R. O, Mezera, R. A. and Le Gier, M, *Proc. Soc. Exp. Biol. and Med.*, 1941, 48, 601
- 2 Lennette, E H, *Proc. Soc. Exp. Biol. and Med.*, 1941, 47, 178
- 3 Kreis, B La Maladie d'Armstrong choro-meningite lymphocytaire Une nouvelle entité morbide? Paris, J B Baillière et fils, 1937, 41
- 4 Traub, E, *Science*, 1935, 81, 298
- 5 Armstrong, C, and Sweet, L K, *Pub. Health Rep., U S P H S*, 1939, 54, 673
- 6 Bugher, J C, Boshell-Manrique, J Roca Garcia, M, and Gilmore, R. M *Am. J. Trop. Med.*, 1941, 21, 309
- 7 Meyer, K. F and Eddie, B *Proc. Soc. Exp. Biol. and Med.*, 1933, 30, 484
- 8 Pawan, J L, *Ann. Trop. Med. and Parasitol.*, 1936, 30, 401
- 9 Shope, R. E., *J. Exp. Med.*, 1935, 62, 85, 101
- 10 Solovjev, V D, *Arch. sc. biol. Moscow*, 1939, 56, 132
- 11 Derrick, E. H., Smith, D J W, Brown, H E, and Freeman, M., *Med. J. Australia* 1939, 1, 150
- 12 Derrick, E H., and Smith, D J W, *Australian J. Exp. Biol. and Med. Sc.*, 1940, 18, 99
- 13 Meyer, K. F, *Am. J. Pub. Health*, 1936, 26, 961
- 14 Andrewes, C H *Proc. Roy. Soc. Med.* 1939, 33, pt. 1, 75
- 15 Meyer K. F, *Harvey Lectures*, 1939-40, 35, 91
- 16 (a) Scott, T F McN, and Rivers, T M, *J. Exp. Med.*, 1936, 63, 397 (b) Rivers, T M, and Scott, T F McN, *J. Exp. Med.*, 1936, 63, 415
- 17 Lennette E H, and Smith M G, *Proc. Soc. Exp. Biol. and Med.*, 1939, 41, 193
- 18 Smadel, J E, Baird, R. D, and Wall, M J, *Proc. Soc. Exp. Biol. and Med.*, 1939, 40, 71
- 19 Smadel, J E, and Wall, M. J, *J. Exp. Med.*, 1940, 72, 389
- 20 Smith T, *Internat. Clin.*, 1931, 3, series 41, 276
- 21 Seastone, C V *J. Exp. Med.*, 1939, 70, 347
- 22 Traub, E *J. Exp. Med.*, 1936, 63, 533, 847
- 23 Armstrong C, *Harvey Lectures*, 1940-41, 38, 39
- 24 Smadel, J E. and Wall, M J, *J. Bact.*, 1941, 41, 421
- 25 Smadel, J E, Baird, R. D and Wall, M J, *J. Exp. Med.*, 1939, 70, 53
- 26 Dalldorf G, *J. Exp. Med.*, 1939, 70, 19
- 27 Casals-Ariet J, and Webster, L. T, *J. Exp. Med.*, 1940, 71, 147
- 28 Armstrong C., and Lillie, R. D, *Pub. Health Rep., U S P H S*, 1934, 49, 1019
- 29 Smith, M G *J. Infect. Dis.*, 1939 64, 307
- 30 Smadel, J E. and Moore, E., *Am. J. Path.*, 1934, 10, 827
- 31 Rivers, T M., Haagen, E., and Muckenfuss, R. S. *J. Exp. Med.*, 1929, 50, 673
- 32 Traub, E., *J. Exp. Med.* 1937, 68, 317



# THE BACTERICIDAL ACTION OF PROPYLENE GLYCOL VAPOR ON MICROORGANISMS SUSPENDED IN AIR. I

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PLATES 18 AND 19

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The idea of employing bactericidal mists as a method for controlling airborne respiratory infection is not new, but until recently no one had succeeded in producing by such means a sterile or relatively bacteria free atmosphere which could be tolerated by human beings. During the past few years new methods of chemical air sterilization have been devised. These consist in the dispersal of germicidal mists containing the effective chemical agents in such small amounts as to be non-detectable or at least unobjectionable to persons in the treated atmosphere. The compounds employed for this purpose are believed to be non-toxic in the minute amounts present in the inspired air.

The initial report on this new approach to the control of air contamination was made by Douglas, Hill, and Smith (1) in 1928. By means of a very fine spray of electrolyzed sea water, containing NaOCl with about 1 per cent available chlorine, these workers were able to effect a marked or complete killing of *Bacillus coli* dispersed in the air. The material appeared to be non-irritating in the concentration employed, which was approximately 1 gm. of the chemical solution in two million cc. of air. This paper apparently attracted little attention and it was not until 10 years later that active development of the subject began.

In 1938 two publications appeared, one by Trillat (2) concerning the properties of germicidal aerosols, and the other by Masterman (3) on air sterilization by spraying or atomizing hypochlorite solutions. Trillat's earlier investigation, covering a period of many years, dealt with problems of droplet infection and the various properties of aerosols, and culminated in his discovery of the sterilizing properties of germicidal aerosols.<sup>1</sup> Trillat found that certain germicidal agents which killed bacteria in the test tube in dilutions not higher than 1:200, were capable of causing death of air-borne bacteria when dispersed in aerosol form in concentrations of 1 gm. of the chemical substance in 5,000,000 cc. of air. He believed that this bactericidal activity was due to direct interaction between the aerosol droplets and the bacterial particles.

<sup>1</sup> Liquid aerosols consist of droplets 1 to 2 $\mu$  in diameter, dispersed in air. An erroneous use of the term aerosol has been introduced by commercial concerns who have applied it as a trade name to certain wetting and detergent compounds.

Trillat tested a number of common bactericidal compounds and found that of these only resorcinol and sodium hypochlorite were satisfactory. The other compounds were either inactive as aerosols or too toxic, or proved to be irritating or unpleasant. He states that resorcinol is the agent of choice as the odor of hypochlorite becomes disagreeable after a time.

Masterman presents evidence for the germicidal effect of fine mists of sodium hypochlorite. He found that 1 gm. of 1 per cent NaOCl atomized in as large a volume as forty million cc. of air would produce sterilization. Masterman concludes that this marked bactericidal action is due to the HOCl gas liberated from the mist and not to an aerosol effect (3, 4).

During 1939 and 1940, two groups of workers in England, Pulvertaft and Walker (5), and Twort, Baker, Finn, and Powell (6), confirmed and extended Trillat's and Masterman's observations. Pulvertaft and Walker tested various substances for activity as germicidal aerosols and recommended a solution of resorcinol in glycerol and water as satisfactory. These workers also found that NaOCl was highly effective and killed air-borne bacteria in a dilution of 1 gm. of 2 per cent NaOCl in six million cc. of air. Their test microorganisms included pathogenic invaders of the respiratory tract as well as non-pathogens. Twort (6) and associates carried out an extensive investigation of the physical properties of aerosols, their droplet size and rate of evaporation, and the effects of various germicidal agents on a number of different microorganisms under a variety of conditions. Their most effective aerosol solution "S<sup>2</sup>" contained 10 per cent hexylresorcinol and 0.05 per cent alkyl sulfate, "lorol," in alkaline propylene glycol. They reported bactericidal effects on certain non-pathogenic microorganisms with extraordinarily small amounts of this material, e.g. 1 gm. to four billion cc. of air.

Andrewes and coworkers (7) published a brief confirmatory report on the use of bactericidal mists for air sterilization, and in addition noted that a few viruses, including that of influenza, are susceptible to the mist action as judged by the reduction of their infectivity for mice.

Twort and Baker (8) have proposed another and quite different type of agent for air sterilization, namely, certain kinds of smokes. Smokes from ignited cardboard soaked with potassium nitrate or from incense were found to be highly effective. They report that 1 gm. of the chemical substance dispersed in smoke form in 500 million cc. of air causes destruction of 95 per cent of air-suspended bacteria within 15 minutes.

Our earlier work in this field consisted in an investigation of the air-sterilizing activity of certain bactericidal substances used as aerosols (9). We first employed certain of the synthetic detergents studied by Miller and Baker (10), since their activity *in vitro* gave promise of greater effectiveness as bactericidal, aerosols than the compounds used by the French and English workers. Preliminary experiments indicated only moderate effectiveness of aqueous solutions of these detergents. However, when the water was replaced by a hygroscopic vehicle such as propylene glycol, the aerosol activity was markedly

increased. We found subsequently that propylene glycol and certain related glycols themselves act as effective bactericidal aerosols.<sup>2</sup>

As the work progressed it was found that propylene glycol in vapor form was highly bactericidal, and that the marked and rapid germicidal action of propylene glycol aerosol was due to vapor liberated from the small glycol droplets. When pure vapor was employed, it was found to be more effective (12) than an equal quantity of propylene glycol dispersed as an aerosol. For the purpose of explicit exposition, the work will be presented in the sequence of its development.

### *Methods and Materials*

*Bacterial Suspensions*—Standardized bacterial suspensions were made by resuspending the centrifugated sediment of an actively growing culture in nutrient broth to a predetermined opacity corresponding to approximately one billion microorganisms per cc. Water and other diluents were employed occasionally. The suspensions were sprayed into the chamber with a Graesser atomizer (14). In some experiments other atomizers producing coarser droplets were used.

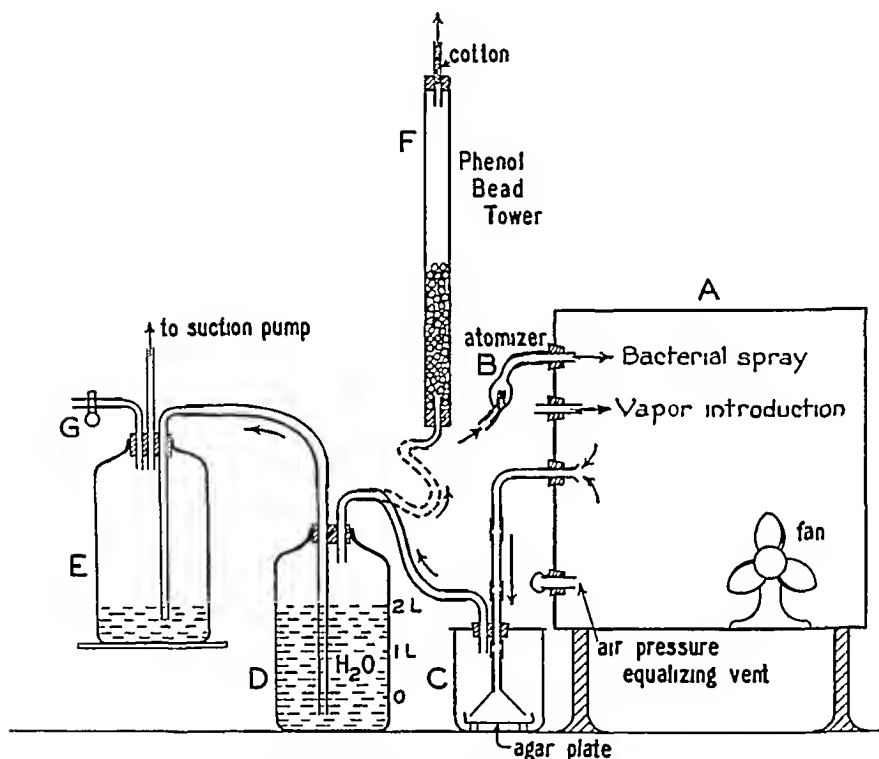
*Media for Recovering Bacteria from Air*—For *Staphylococcus albus* and most other non-pathogens nutrient agar with 0.5 per cent added dextrose was used. Rabbit blood agar was employed for recovering pneumococci and *Streptococcus viridans*, sheep blood agar for hemolytic streptococci and staphylococci and chocolate agar for *Hemophilus influenzae*. It was found that chilling the agar plates before use resulted in maximum recovery of bacteria from the air samples.

*Test Chambers*—The chambers were made of glass and metal as shown and described in Text fig. 1. Wooden chambers were found to be somewhat less satisfactory. The air was gently agitated by means of a small fan rotating at a rate sufficient to produce detectable air movement in all parts of the chambers. A metal fan with 4 blades each 2½ inches long run at 75 volts by means of a variable transformer which gave a speed of 500 R.P.M., proved satisfactory for this purpose. The fan was run for a period of only 5 minutes after the introduction of the bacterial spray.

*Method of Sampling Air*—The number of viable bacteria recoverable from the chamber air was determined by withdrawing a measured volume of air at a constant

<sup>2</sup> Although the English workers used glycols and glycerin as vehicles, they apparently ascribed little or no importance to these compounds beyond their usefulness as hygroscopic solvents for the germicidal substances, resorcinol and hexylresorcinol. The only reference to a possible independent action of propylene glycol is that made by Twort and coworkers (6), who reported a single experiment in which solutions of propylene glycol in alcohol exerted a very high degree of bactericidal activity when dispersed in mist form. It seems probable, however, that the germicidal action of this mixture was principally due to the alcohol, since alcohol vapor itself possesses marked germicidal properties. Furthermore, Baker and Twort state in a recent paper (13) that the presence of propylene glycol in their S<sup>2</sup> mixture contributes little or nothing to its bactericidal activity.

rate (2 liters in 2 minutes) through a glass funnel which was suspended directly above the surface of an agar plate within a sealed glass jar (Text-fig 1) This is a modification of the technique of air sampling described by Hollaender and DallaValle (15) The rubber and glass connections are made as short as possible. The air vent for equalizing internal and external pressure is covered with one or two layers of cotton



TEXT-FIG 1 Apparatus employed for determining bactericidal activity of glycol vapors A, 60 liter air-tight glass-walled chamber with one metal wall (opposite the side with vents) fitted with a door closing on rubber gaskets (All sides, 15 inches square) The three upper orifices are actually on a horizontal line across the center of the wall B, Graeser atomizer connected with inlet by rubber tube C, sampling jar G, air vent allowing water to return from bottle E to D

flannel When pathogenic microorganisms were being studied, the orifices of the sampling jars were clamped and the jar containing the agar plate placed in the incubator Before opening, a considerable volume of air was drawn through the jar and passed through a bead tower containing phenol (Text-fig 1) Likewise, after each sampling the air from the measuring bottle was expelled through phenol in the bead tower At the end of experiments with pathogens, the chambers were filled with propylene glycol aerosol or vapor and this air drawn through the suction bottles Canton flannel masks were worn as an added precaution



*Propylene Glycol*—The propylene glycol used in this study<sup>3</sup> was clear, colorless, and odorless, and when fractionated at a pressure of 25 mm., more than 80 per cent of the material was collected at a temperature of 99–101°C. (The boiling point given in the literature is 100–101.8°C at 24 mm.) Propylene glycol is relatively non volatile—its normal boiling point is 188°C, and at 20°C its vapor pressure is 0.18 mm. Hg. Thus a concentration of 0.73 mg per liter in the vapor state represents atmospheric saturation. No difference in behavior was detectable when the stock propylene glycol or the redistilled material was used in the experiments described in this paper.

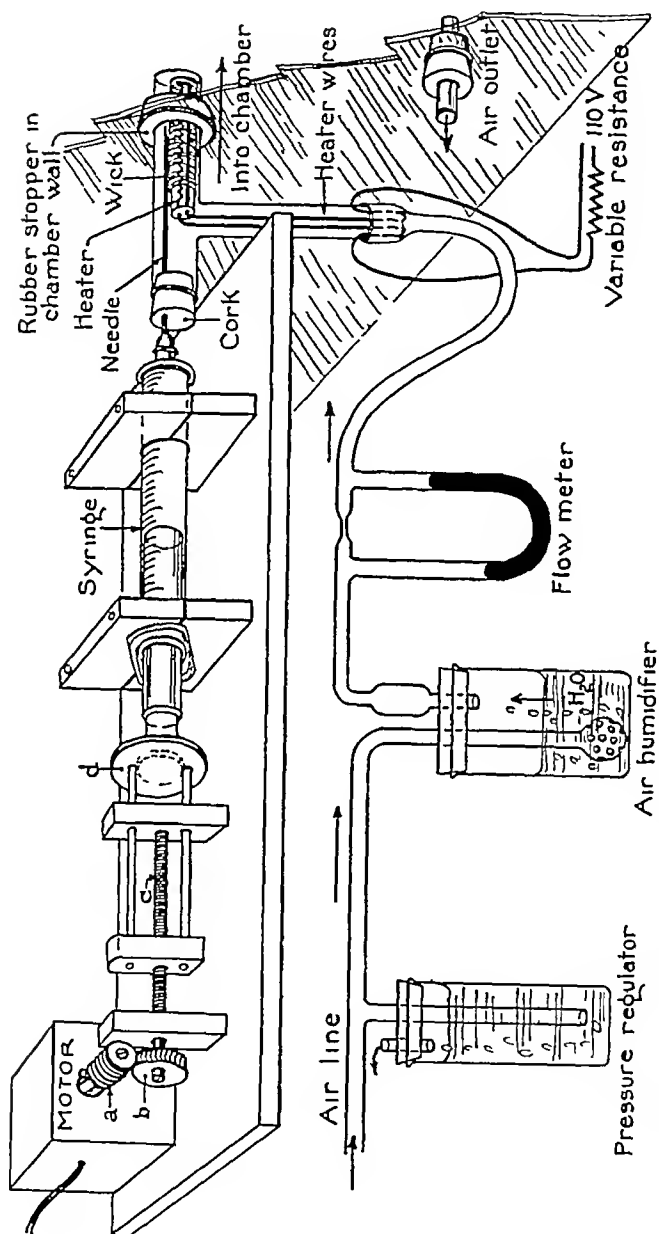
*Production of Propylene Glycol Aerosol*.—An effective aerosol was produced by means of the Graesser atomizer which delivers a dry mist consisting of droplets averaging 2 to 3  $\mu$  in diameter. The DeVilbiss atomizer No. 180 is also satisfactory.<sup>4</sup>

*Production of Propylene Glycol Vapor*.—The preparation of atmospheres containing various concentrations of propylene glycol in the vapor state was accomplished in a number of different ways. Placing the glycol in three Petri dishes on the floor of the chambers, and allowing it to evaporate overnight (for 14 to 16 hours) results in a vapor concentration of 0.35 mg per liter, a quantity sufficient to produce almost immediate killing of the various organisms tested in this study. More rapid and complete saturation is effected by pouring propylene glycol, heated to 70–80°C, into three Petri dishes placed in the chamber. The chamber is sealed, and allowed to cool to room temperature while a fan circulates the air inside. Still another method used consisted in filling the chamber with air bubbled through propylene glycol heated to 60°C (in a thermostated water bath), which resulted in a glycol concentration of 0.66 mg per liter in the vapor state.

In order to achieve a more rapid and accurate means of filling the chambers with any desired concentrations of propylene glycol the apparatus shown in Text fig. 2 was constructed. A 60 cycle synchronous motor of 1 R.P.M. speed drives forward a screw (c) of 20 threads per inch by means of a worm drive (a) and gear (b), (ratio 7½:1) causing plate (d) to move forward and advance the plunger of a syringe. Propylene glycol contained in the syringe is forced out at a constant rate on to a heater which volatilizes the material. The heater consists of a 75 ohm, 10 watt "ohmite" resistor, across which 30 volts are applied. The needle of the syringe rests on a wick made up of a strip of cotton tape wound around the porcelain covering of the resistor. The wick serves to disperse the liquid over the hot surface. An air stream whose rate of flow is controlled by a pressure regulator and measured by a calibrated flow meter, impinges on the heater and carries the volatilized glycol into the chamber. The glass T tube (inner diameter 15 mm.) in which the heater is contained must be as short as possible to obviate the possibility of condensation of the glycol on the walls before it has been adequately mixed with the incoming air stream. Humidity is controlled by a humidifier placed in the path of the air stream, as shown in Text

<sup>3</sup> We are indebted to the Carbon and Carbide Co. for supplying us with this highly purified material. It should be pointed out that there are preparations of propylene glycol on the market which contain impurities in toxic amounts.

<sup>4</sup> We wish to express our appreciation to the DeVilbiss Co. for making a special experimental atomizer for us.



TEXT-FIG 2 Apparatus for the introduction of air containing calculated concentrations of glycol vapor

fig 2 The relative humidity can be varied either by changing the temperature or the amount of the water in the humidifier. Relative humidity inside the chamber was measured by means of wet and dry bulb thermometers, with the wet bulb placed opposite the fan.

The concentration of propylene glycol vapor in the mixture issuing from the T tube is readily calculated, since both the rate of delivery of liquid propylene glycol and the rate of air flow through the vaporizer are known. Any desired concentration may be secured either by changing the rate of flow of air through the flow meter, or by inserting a syringe of a different diameter in the syringe holder. One cc. and 2 cc. syringes were found to be most suitable.

The gas stream fed into the chamber is mixed completely with the air already present by means of a rapidly rotating electric fan and then passes out through an escape vent. A volume of gas four times that of the chamber is swept through for each filling. (Calculation shows that after four air changes under these conditions the propylene glycol content of the gas inside the chamber is 99.0 per cent of that in the entering air stream.) The chamber is then sealed off. Before beginning the experiment a sample of air is removed for analysis as an additional check on the glycol concentration.

*Method of Determining Concentration of Propylene Glycol Vapor in Air*—The determination of the concentration of propylene glycol vapor was accomplished by withdrawing a 2 liter sample of the air and bubbling it through 10 cc. of water with the aid of a fairly porous fritted glass gas-disperser. Complete absorption of the propylene glycol is obtained at a sampling rate of 1/5 liter of air per minute.

The propylene glycol content of the resulting solution can be analyzed by the method of Lehman and Newman (16), modified to accommodate the smaller concentrations involved (17). In this reaction the propylene glycol is quantitatively oxidized by a standard amount of periodic acid. The remainder of the oxidizing agent is determined by reduction with a known quantity of sodium arsenite, and the excess arsenite titrated with  $I_2$ . The contents of the test tube are quantitatively washed into an Erlenmeyer flask. 10 cc. of  $M/10$  periodic acid<sup>4</sup> is added, and the sample is placed in an ice box for 15 minutes. At the end of that time, 5 cc. of 7 per cent  $NaHCO_3$  is added, then 2.5 cc. of  $N/10 Na_3AsO_3$ , followed by 0.4 cc. of freshly prepared 20 per cent KI. The solution is allowed to stand for 15 minutes at room temperature, after which 1 cc. of 1 per cent starch is added. The solution is then titrated with 0.01  $N I_2$  to the end point marked by the appearance of the blue color of the starch iodine complex. A blank is run through the same procedure, and the number of milliliters of  $I_2$  solution used in the blank is subtracted from that required by the sample. One cc. of 0.01  $N I_2$  solution is equivalent to 0.38 mg. of propylene glycol. Samples containing known amounts of propylene glycol varying from 0.3 to 1.0 mg. gave results accurate to within 0.04 mg. when analyzed by this method.

<sup>4</sup> The  $M/10$  periodic acid is prepared by dissolving 5.35 gm. of sodium periodate ( $NaIO_4$ ) in 75 cc. of  $N/1$  sulfuric acid, and diluting to 250 cc. in a volumetric flask. The resulting solution is stable indefinitely if stored in an ice box between runs. Directions for preparation of the standard sodium arsenate and iodine solutions are available in any standard textbook such as Pierce, W. C., and Haensch, E. L., *Quantitative analysis*, New York, John Wiley & Sons, 1937.

## EXPERIMENTAL

*Reproduceability of Bacterial Counts in Air Samples*—Agar plates exposed to the flow of bacteria-containing air by means of the technique outlined above yielded a remarkably uniform distribution of bacterial colonies. Even though the bacteria recovered on the agar surface represented only a very small per cent of the numbers sprayed into the chamber, the results of sampling were relatively constant. Table I gives the results of air samples taken from two chambers following the introduction of the same amount of standardized suspension of *Staphylococcus albus*.

TABLE I

*Control on Method of Taking Samples from Enclosed Atmospheres into Which the Same Amount of Bacterial Suspension Has Been Sprayed*

Dilution of standard suspension and time sprayed	Suspension No	Test No	Chamber No	Colonies on plate samples taken	
				Immediately	After 5 min.
1 10 for 30 sec	1	1	III	364	237
		2	IV	343	283
		3	IV	312	266
	2	1	III	328	250
		2	IV	311	242
	1 5 for 45 sec	3	1	III	1154
2			IV	1254	878
4		1	IV	910	658
		2	III	922	566
		3	IV	948	636

Two different standard suspensions of staphylococcus were made up from the same culture on each of two occasions. The dilutions of the standard suspensions and the time of spraying are indicated in the first column of the table. The same atomizer filled to the same level and operated at 500 mm air pressure was used in all the tests. Air samples (of 2 liters each) were withdrawn at exactly the same intervals following termination of the bacterial spray. The first sample (labeled immediately) was started 15 seconds afterwards and the second one at 5 minutes. After two samples had been taken, the chamber was cleaned out and the next test run under identical conditions.

It will be noted in the table that suspensions 1 and 2 yielded approximately the same number of colonies on the plates while the difference in sampling yields between suspensions 3 and 4 indicates that we were less successful in making up suspensions of equal density.

There is a progressive and quite constant diminution in the number of colonies recovered from successive air samples during the period of an hour, as illustrated in Plate 18, Figs 1 to 4. This phenomenon may be ascribed to settling of the bacterial droplets, inelastic collisions with the chamber walls, and natural mortality of the bacteria. This necessitated the use of two identical chambers for each experiment, one for the test, the other as a control.

### *Propylene Glycol Aerosol*

Tests on the bactericidal activity of propylene glycol aerosol were performed as follows: usually the bacteria were sprayed into the chamber first, and an air sample obtained, following which a weighed quantity of the aerosol was introduced. In order to control any possible effect of the germicidal aerosol other than its direct bactericidal action, distilled water was sprayed into the control chamber in each experiment. It was found that a concentration of

TABLE II  
*Effect of Propylene Glycol Aerosol on Staphylococcus albus*

Aerosol concentration	Time intervals of air samples	No. of colonies on plates from	
		Control chamber	Test chamber
1:2,000,000	Immediately after bacterial spray	2140	2124
	Immediately after H <sub>2</sub> O in control and aerosol in test	1940	3
	15 min. later	510	0
	30 min. later	350	0

1 gm. of propylene glycol aerosol in two million cc. of air effected complete sterilization of an atmosphere into which as many as 500,000 bacteria per liter of air had been sprayed. Furthermore, this action occurred with surprising rapidity. Air samples taken within a few seconds after the introduction of the aerosol yielded sterile plates while similar plates from the control chamber showed many hundreds or thousands of colonies depending on the amount of bacterial suspension used. A protocol of an experiment with *Staphylococcus albus* is recorded in Table II and photographs of another experiment are shown in Plate 18, Figs 1 to 8.

A number of other microorganisms were found to be similarly susceptible to the action of this aerosol. Among those tested were pathogenic invaders of the respiratory tract, *Streptococcus pneumoniae* Types I and III, hemolytic streptococci, and hemolytic staphylococci, as well as organisms of lesser or no pathogenicity, such as *Streptococcus viridans*, *Bacillus coli*, *Micrococcus catarrhalis*, and *Bacillus subtilis* (vegetative form).

The order of introduction of the bacteria and the propylene glycol into the

chamber was found to have no effect on the result. Thus an equally rapid sterilization was obtained when bacteria were introduced into a test chamber already containing propylene glycol. Other glycols, such as ethylene and trimethylene, acted about as effectively as propylene glycol. Glycerin, on the other hand, exhibited only a slight killing effect.

### *Propylene Glycol Vapor*

(a) *Bactericidal Effect of Aerosol Not Explainable on Basis of Droplet Interaction*—If the disappearance of bacteria in air treated with a propylene glycol mist represents a true bactericidal effect, and evidence presented later indicates that such is the case, how can this action be explained? The means by which bactericidal mists produce a lethal concentration of the active agent in the immediate environment of the bacteria would seem to be limited to two possibilities, (a) direct contact between germicidal aerosol droplets and bacterial particles, (b) production of sufficient vapor or gas by evaporation from the germicidal droplets to permit rapid and abundant collision of gas molecules with the bacterial particles. Trillat, Pulvertaft and Walker, and Twort and his associates, believe that germicidal mists exert their antibacterial action exclusively as aerosols. They state that the substances employed by them are ineffective in the gas phase. In fact, their investigations of different agents or mixtures for use as bactericidal aerosols have been directed toward developing a mist with a very slow rate of evaporation. Masterman, on the other hand, considers that the activity of the germicidal mist he employed, namely NaOCl, is due to the liberation of HOCl gas.

Calculations of the maximum number of contacts possible between aerosol and bacterial droplets (which Twort *et al.* have made (6) and which we have repeated) indicate that it would take between 2 and 200 hours for sterilization to occur if this were the mode of action of the germicidal aerosol. Since complete sterilization of a heavily contaminated atmosphere has been found to take place in as short a time as 5 minutes by the English workers, and within a matter of seconds by ourselves, the rate of interaction between the bactericidal agent and air-suspended bacteria must be of an entirely different order of magnitude. Such rapid interaction could occur only if the germicidal substance were present in the gas phase.

(b) *Postulation of Vapor-Droplet Effect*—Granted that rapid interaction between gas molecules and droplets does occur, would the resulting concentration of propylene glycol in the bacterial droplets be sufficient to produce the striking bactericidal effects observed? Experiments *in vitro* showed that propylene glycol in common with other closely related glycols exhibited relatively low germicidal action. Certain microorganisms grow well in broth containing as much as 5 to 15 per cent of the different glycols tested (propylene, ethylene, and trimethylene). The pneumococcus, for example, grows in

broth containing up to but not more than 5 per cent propylene glycol *Staphylococcus albus* is not inhibited until a concentration of more than 10 per cent of this material is reached. However, when these bacteria are suspended in 80 to 90 per cent propylene glycol, they are killed immediately. Since propylene glycol possesses a marked affinity for water, rapid absorption of the vapor by aqueous droplets might be expected to occur. Indeed, calculations show that with vapor concentrations even considerably below the saturation value of propylene glycol, the number of collisions between gas molecules and droplets containing bacteria is sufficient to produce almost instantly, a lethal concentration (70 to 80 per cent) of propylene glycol in the droplets. Furthermore, the observed rate of evaporation of droplets of a propylene glycol mist is so rapid that a relatively high vapor concentration is liberated within a second or two.<sup>6</sup>

TABLE III  
*Effect of Propylene Glycol Vapor on Streptococcus hemolyticus*

Vapor concentration	Time intervals of air samples	No. of colonies on plates from	
		Control chamber	Test chamber
1 7,700 000	Immediately after bacterial spray	3/0	36
	5 min. later	360	5
	15 min. later	312	0
	30 min. later	250	0
	60 min. later	96	0

(c) *Demonstration of the Bactericidal Activity of Propylene Glycol Vapor*—Tests carried out under conditions identical with those in which the aerosol was employed, showed that propylene glycol vapor was not only highly bactericidal but acted more effectively than did the aerosol of this substance. In carrying out such experiments the chamber was filled with glycol vapor of known concentrations by means of one of the several methods described, following which the bacterial suspension was introduced. Concentrations of not less than 1 gm. of propylene glycol in three or four million cc. of air resulted in immediate and complete sterilization of the chamber air. This effect was demonstrated with staphylococci, pneumococci, hemolytic streptococci, *H. influenzae*, and *H. pertussis*. The results of an experiment in which pneumococcus Type I was employed as the test organism are exhibited in Plate

<sup>6</sup> The size and rate of evaporation of the droplets was determined by means of the Millikan oil-drop apparatus (18). These calculations together with a detailed discussion of the physicochemical interactions of propylene glycol gas molecules and fine fluid droplets will be presented elsewhere.

19, Figs 1 to 6 With diminishing concentrations of propylene glycol, immediate and marked bactericidal activity was still obtained, although complete sterilization of the air required increasing intervals of time Table III shows the lethal action of a vapor concentration of 1 7,700,000 (0.13 mg per liter) on *Streptococcus hemolyticus* The effectiveness of low concentrations of propylene glycol vapor was found to depend also on other variable factors, such as numbers of microorganisms dispersed into the air, the number of bacterial droplets, humidity of the atmosphere, state of bacterial suspension, etc A detailed presentation of this phase of the work will be given in a second paper Suffice it to say here that under optimum conditions pronounced bactericidal action of propylene glycol vapor against certain of the respiratory pathogens could be demonstrated in concentrations as small as 1 gm of the glycol in 50,000,000 cc of air

Propylene glycol vapor was also found to exert a lethal or at least an inactivating effect on the virus of influenza This was determined by tests in which the presence of the glycol vapor in concentration of 1 3,000,000 was shown to protect mice completely against infection with amounts of air-borne influenza virus that produced death regularly in the control animals (19)

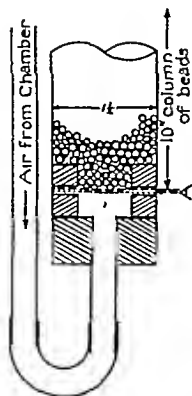
#### *Tests with Other Glycols*

Experiments with other glycols in vapor form revealed variations in their bactericidal activity Ethylene glycol, 2,3-butylene glycol, trimethylene glycol, and a number of compounds of related chemical composition were found to be highly effective The relationship between chemical structure and bactericidal properties will be discussed in detail in a later communication dealing with the mechanism of the action of glycol vapors

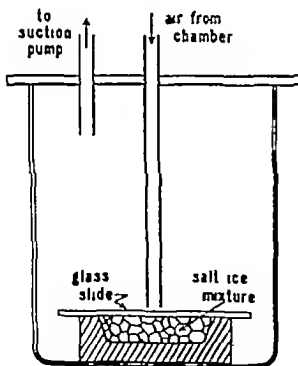
#### *Evidence for the Bactericidal Action of Propylene Glycol*

Other workers in this field have assumed that lack of growth on agar surfaces exposed to bacteria-laden atmospheres treated with germicidal mists represents actual death of the bacteria in the air It seemed to us, however, that further experimental evidence was necessary to exclude the possibility that some factor or factors present in the air containing the germicidal mist or vapor might either inhibit growth or prevent adherence of the bacteria on the agar surface In order to test for any growth-inhibiting effect due to condensation of the glycol itself on the collecting plates, the following control was performed agar plates were exposed directly to air saturated with propylene glycol vapor or to the glycol spray from an atomizer, then used in taking samples from the control chamber They yielded just as many colonies as plates not treated with glycol The possibility that the reaction between the propylene glycol vapor and the bacterial droplets might somehow change the





TEXT FIG 3 Bead tower for collection of bacteria from chamber air. 20 to 25 cc. of broth diluted with equal parts of sterile water is placed in a 20 inch glass cylinder half filled with 3 mm. glass beads. This tower differs from that shown in Text fig 1 in that there are two monel metal screens of 24 and 70 mesh inserted at A.



TEXT FIG 4 Device for collecting air-borne bacteria on a glass slide.

state of suspension of the latter and prevent their adherence to the agar surface was tested by employing another method of collecting the vapor treated bacteria. Air from the chamber was drawn slowly through 25 to 50 cc of diluted nutrient broth in a glass cylinder containing many small glass beads (Text-figs 1 and 3). Plated samples of this fluid, through which air from the control chamber had been bubbled, yielded a large number of colonies, whereas samples of fluid through which the glycol-containing air had been drawn were sterile.

TABLE IV

*Inoculation of Mice with Pneumococcus Type I Exposed to Propylene Glycol Vapor*

	Material introduced into chamber	Air samples		No of pneumococcus colonies		Mice inoculated with 1 cc. of fluid from bead tower
		Time taken	Method of culture	On plate	In fluid from bead tower	
Test chamber	Propylene glycol vapor 1 3,000,000 followed by pneumococcus spray	Immediately after bacterial spray	Plate	0	0	10 mice All remained well
		10 min. later	Bead tower			
		30 min later	Plate	0		
Control chamber	Pneumococcus spray	Immediately after bacterial spray	Plate	1128	1 cc. = 228 Total = 5700*	10 mice All died of pneumococcus infection in 24 to 36 hrs.
		10 min later	Bead tower			
		30 min later	Plate	484		

\* The 2 liter air sample was drawn through 25 cc. of 50 per cent broth-water mixture

The presence of killed bacteria in the glycol-treated air was demonstrated by condensing the moisture of the air drawn from the chamber on a chilled microscope slide, as shown in Text-fig 4. When these preparations were stained, the bacteria appeared normal. Cultures of the condensed fluid on agar and in broth showed no growth.

We have also eliminated the possibility that microorganisms, although rendered incapable of growth on artificial media, might retain their capacity to reproduce in a suitable host. Experiments were conducted in which highly virulent pneumococci Type I were sprayed into a chamber containing the propylene glycol vapor. The air was then drawn through sterile broth in a bead tower and 1 cc quantities of this fluid were injected into mice. These

animals survived. However, when the procedure was performed with air drawn from the control chamber, all the mice died of pneumococcal infection. The protocol of an experiment of this type is shown in Table IV.

Further evidence of the bactericidal action of propylene glycol vapor was provided by cultures made from the floor and walls of the chamber at the end of the experiment. Whereas cultures from the control chambers always yielded large numbers of bacteria, those from the test or glycol treated chamber were uniformly sterile.

#### *Additional Data and Comments*

The question as to how propylene glycol produces its rapid and marked bactericidal effect has not been elucidated. However, certain observed characteristics of the glycol treated microorganisms indicate something of the general nature of the effect. Gram positive bacteria killed by exposure to propylene glycol, either in vapor or liquid form, retain their Gram positiveness as well as their morphological integrity. Glycol killed pneumococci show typical capsular swelling in the presence of specific antipneumococcal rabbit serum and retain their antigenic properties. Mice, vaccinated with pneumococci killed by propylene glycol, were found to be just as resistant to the injection of living microorganisms as were mice similarly immunized with heat killed pneumococci. While pneumococci suspended in propylene glycol retain their Gram positiveness for many weeks or months, removal from this medium results in their becoming Gram negative. Such microorganisms freed from the glycol undergo gradual dissolution. Autolysis is hastened by the presence of bile salts. The change from the Gram-positive to the Gram negative state can be brought about by simply adding an equal volume of water or physiological salt solution to the glycol suspension. These findings indicate that propylene glycol inhibits but does not destroy the autolytic enzyme system of the pneumococcus cell. Whether or not the other enzyme systems of the pneumococcus are affected remains to be determined.

We have not made comparative studies of the effectiveness of propylene glycol and the several compounds and mixtures previously employed by other workers, except in the case of Twort's "S". Our observations with "S" (10 per cent hexylresorcinol in alkaline propylene glycol) have been confined to tests on *Staphylococcus albus*. These experiments showed that the addition of hexylresorcinol to propylene glycol increased markedly the bactericidal activity of the latter substance. The difference between the two agents both in aerosol and vapor forms was slight as judged by the immediate sterilizing effect, but became apparent after 5 to 15 minutes. An increased lethal action might have been anticipated from the presence of hexylresorcinol since, *in vitro*, this substance has been shown to be bactericidal in dilutions of between 1/2,000 and 1/20,000 (depending on the manner of testing) in contrast to

propylene glycol which requires a concentration of 1:1, i.e., equal parts of bacterial suspension and glycol to produce a similar effect. Even higher concentrations of propylene glycol were needed to kill certain non-pathogenic microorganisms. Since rapidity of action of the air sterilizing agent would seem to be of great importance in the application of such a method to the control of air-borne droplet infection, and since the addition of hexylresorcinol appears to contribute little to the immediate bactericidal effect of propylene glycol, we feel that for this and other reasons the use of the latter substance alone is to be preferred. However, it may be desirable to employ, for certain purposes, highly bactericidal agents such as hexylresorcinol even though they possess much greater potential toxicity than does propylene glycol.

Atmospheres containing propylene glycol vapor in concentrations up to the saturation point (0.7 mg. of glycol per liter of air or 1:1,400,000) are invisible, odorless, non-irritating, and tasteless, except in the highest concentrations when a faintly sweetish taste is detectable. Tests on the toxicity of propylene glycol administered by the usual routes, i.e., oral and intravenous, have shown this substance to be essentially non-toxic (20). While it would seem probable that propylene glycol taken into the body by way of the respiratory tract would be equally innocuous, such an assumption is not justifiable in the absence of direct experimental evidence. We have carried out tests on the effect of maintaining rats in atmospheres of propylene glycol vapor for a year or more. The results of these experiments will be presented in the second paper.

#### SUMMARY

It has been found that propylene glycol vapor dispersed into the air of an enclosed space produces a marked and rapid bactericidal effect on microorganisms introduced into such an atmosphere in droplet form. Concentrations of 1 gm. of propylene glycol vapor in two to four million cc. of air produced immediate and complete sterilization of air into which pneumococci, streptococci, staphylococci, *H. influenzae*, and other microorganisms as well as influenza virus had been sprayed. With lesser concentrations of propylene glycol, rapid and marked reduction in the number of air-borne bacteria occurred, but complete sterilization of the air required a certain interval of time. Pronounced effects on both pneumococci and hemolytic streptococci were observed when concentrations as low as 1 gm. of glycol to fifty million cc. of air were employed.

Numerous control tests showed that failure of the glycol-treated microorganisms to grow on the agar plates was due to actual death of the bacteria. The means by which propylene glycol vapor produces its effect on droplet-borne bacteria is discussed and data relating the bactericidal properties of propylene glycol *in vitro* to the lethal action of its vapor is presented.

Atmospheres containing propylene glycol vapor are invisible, odorless,

and non irritating This glycol is essentially non toxic when given orally and intravenously Tests on possible deleterious effects of breathing propylene glycol containing atmospheres over long periods of time are being carried out

## BIBLIOGRAPHY

- 1 Douglas S R., Hill L., and Smith, W., *J Ind Hyg*, 1928, 10, 219
- 2 Trillat M A. *Bull Acad mtd*, 1938, series 3, 119, 64
- 3 Masterman, A. T., *J Ind Hyg*, 1938 20, 278.
- 4 Masterman, A T., *J Hyg*, Cambridge, Eng 1941, 41, 1, 44
- 5 Pulvertaft, R. J V., and Walker, J W., *J Hyg* Cambridge, Eng, 1939, 39, 696
- 6 Twort, C C., Baker, A. H., Finn, S R., and Powell, E O., *J Hyg*, Cambridge Eng, 1940, 40, 253
- 7 Andrevess, C H., *Lancet*, 1940, 2, 770
8. Twort, C. C and Baker, A H., *Lancet* 1940 2, 587
- 9 Robertson, O H, Bigg E., Miller, B F, and Baker Z., *Science*, 1941, 93, 213
- 10 Miller, B F, and Baker Z. *Science*, 1940, 91, 624
- 11 Robertson, O H, Bigg E., Miller B F Baker Z., Puck, T T, *Tr Assn Am Physn*, 1941
- 12 Robertson, O H. Bigg, E., Miller B F, Puck, T T, and Baker Z., in Moulton F R. *Aerobiology symposium*, The American Association for the Advancement of Science 1942, No 17, in press.
- 13 Baker A. H and Twort, C. C., *J Hyg*, Cambridge, Eng 1941 41, 117
- 14 Graeser, J B., and Rowe, A. H., *Am J Dis Child*, 1936, 52, 92
- 15 Hollaender, A and DallaValle J M., *Pub Health Rep, U S P H S*, 1939, 54, 1, 574
16. Lehman A. J., and Newman, H. W., *J Pharmacol and Exp Therap*, 1937, 60, 312
- 17 Puck, T T, *Science*, 1942, 95, 178
- 18 Millikan, R. A., *The electron*, Chicago The University of Chicago Press, 1924, 90
- 19 Robertson, O H, Loosli, C G, Puck T T, Bigg, E., and Miller, B F, *Science*, 1941, 94, 612
- 20 Hanzlik, P S, Newman, H. W, Van Winke, W, Lehman, A. J and Kennedy N K. *J Pharmacol. and Exp Therap*, 1939, 67, 101

## EXPLANATION OF PLATES

## PLATE 18

FIGS 1 to 8 The effect of propylene glycol aerosol on *Staphylococcus albus* The same quantity of a 1:10 dilution of the standard bacterial suspension was sprayed into each chamber Figs 1 to 4 are photographs of plate samples taken from control chamber Figs 5 to 8 show the results of air samples taken before and after the introduction of propylene glycol aerosol in a concentration of 1 gm of glycol in 2,000,000 cc of air Plate 6 showed only one colony 7 and 8 were sterile The air samples represented by plates 2 and 6 were begun within 2 or 3 seconds after the termination of the water and glycol mists respectively

## CONTROL CHAMBER

## TEST CHAMBER

Immediately  
after  
bacterial  
spray

Immediately  
after  
water mist  
←  
and  
propylene  
glycol aerosol  
→

15  
minutes  
later

30  
minutes  
later

### PLATE 19

FIGS 1 to 6 The effect of propylene glycol vapor on pneumococcus Type I equivalent amounts of a 1:20 dilution of the standard bacterial suspension were sprayed into each chamber. Figs 1 to 3 show plates exposed to air samples from the control chamber. Plates exposed to air samples from the test chamber which was filled beforehand with air containing propylene glycol vapor in a concentration of approximately 1 gm. of glycol in 3,000,000 cc. of air, were uniformly sterile, Figs 4 to 6

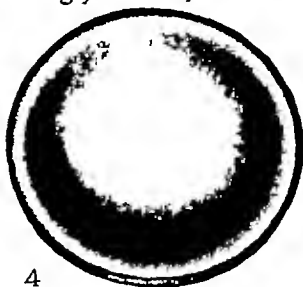


CONTROL CHAMBER

TEST CHAMBER  
filled with propylene  
glycol vapor

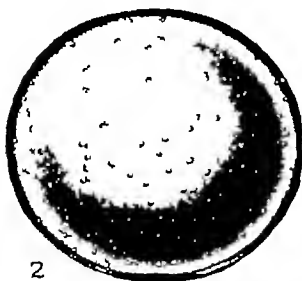


1



4

IMMEDIATELY AFTER BACTERIAL SPRAY



2

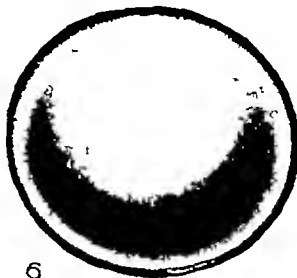


5

5 MINUTES LATER



3



6

15 MINUTES LATER



## STUDIES IN RODENT POLIOMYELITIS

### I. FURTHER EXPERIMENTS WITH THE MURINE STRAIN OF SK POLIOMYELITIS VIRUS\*

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In 1940, we reported the successful adaptation of the SK strain of human poliomyelitis virus from the *rhesus* monkey to white mice by way of intermediary passage through cotton rats (1). A close relationship between the adapted virus and monkey poliomyelitis virus was suggested by similarities in the symptomatology and pathology of the infection in monkeys and rodents as well as by the trend of serological cross neutralization tests. The SK murine virus, in some respects, resembled the Lansing mouse strain of poliomyelitis virus previously described by Armstrong (2) and the RMV and Philadelphia mouse strains of poliomyelitis virus which were later adapted by Toomey (3). It differed, however, from these other rodent strains in that it combined an extraordinary degree of virulence for mice with little or no pathogenicity for *rhesus* monkeys.

The fact that various murine strains of poliomyelitis virus exhibit divergent properties need cause neither surprise nor concern. What differences there are may readily be accounted for, provided one is prepared to regard the artificially induced transmission of poliomyelitis virus from its natural to an unnatural host not as a simple, straight transfer of virus but as a phenomenon of biological adaptation. In this process different virus strains may lose old and gain new properties in proportion to the extent of the occurring transformation. Thus, with virus only partially adapted, residual virulence for the original host would be retained and blended with low virulence for the new host into a bivalent agent of dual pathogenicity, if, on the other hand, the adaptive process progresses to an ideal end point, the original virulence may conceivably be lost in a total exchange against the newly acquired virulence, leaving a strictly monovalent pathogenic agent.

The SK murine virus, since the time of its isolation, has been maintained in two parallel lines of propagation, *i.e.* by serial transfer in tissue culture and by intracerebral passage in mice. During more than 200 consecutive passages *in vitro* the tissue culture virus has preserved its original potency for mice and,

\* Aided by a grant from the Philip Hanson Hiss, Jr., Memorial Fund.

at no time, has given rise to paralysis in animals other than mice or cotton rats. The mouse passage virus, on the other hand, during a similar number of animal passages, has gradually increased in virulence for mice from an initial titer of about 1:1 million to a maximum titer of about 1:1 billion dilution activity, as determined by intracerebral tests. When reexamining murine virus of later mouse passages for pathogenicity in other laboratory animals it was found that this virus, after having been transmitted through 70 mouse passages, was capable of producing flaccid paralysis in guinea pigs (4). A detailed description of this guinea pig paralysis will be found in another paper of the current series of communications (5). The present paper offers new data concerning certain properties of murine virus obtained from remote mouse passages which have hitherto not been reported. These data include first, a reexamination of the pathogenicity of murine virus for *rhesus* monkeys and rabbits, second, an appraisal of age as a factor conditioning natural resistance of mice to infection and reinfection with murine virus, third, an investigation of seasonal fluctuations in the susceptibility of mice to murine infection, and fourth, further studies of the murine virus by means of immunological methods.

#### *Pathogenicity of Murine Virus from Remote Mouse Passage for Monkeys and Rabbits*

(a) *Pathogenicity for Rhesus Monkeys*—It will be recalled that murine virus, in its earlier passages, had failed to bring about paralysis in *rhesus* monkeys. However, the available data indicated that the virus, especially when introduced by intracerebral injection, was not altogether harmless for monkeys even though it fell short of producing typical poliomyelitis.

After transmission through 70 mouse passages, the murine virus gave signs of more definite activity in the central nervous system of infected monkeys. Thus, of a group of 13 monkeys injected intracerebrally with brain or cord of paralyzed mice, 1 monkey developed extensive pareses and 5 monkeys passed through a well defined encephalitic syndrome consisting of high fever, coarse tremor, and tonic-clonic convulsions, followed by extreme prostration which proved fatal in two instances. The described symptoms, together with the pathological examination of the two fatal cases, suggest that the infectious agent is capable of localizing in the monkey brain with the production of an acute polioencephalitis. Yet none of these animals can be said to have developed "classical" poliomyelitis if this diagnosis be limited to a disease characterized by spinal localization of the virus with subsequent production of flaccid paralysis. Moreover, the observed process differed from true poliomyelitis in that transmission to new monkeys failed, whereas transfers to mice were positive, furthermore, monkeys which were permitted to survive failed to resist subsequent reinfection, 4 weeks later, with SK monkey poliomyelitis virus.

Additional data concerning the pathogenic potentialities of mouse virus for

*rhesus* monkeys are available from experiments in which *rhesus* monkeys received a series of repeated injections of large doses of mouse virus by the intravenous route, extending over a period of 5 days. These experiments will be reported in detail elsewhere. Suffice it to state here that in a group of 14 monkeys thus treated there were 2 animals which presented partial or complete flaccid paralysis strictly limited to the right leg, on the 5th day when the last dose of murine virus was injected. Upon intracerebral reinfection with poliomyelitis monkey virus (0.5 cc 1:10 dilution of RMV strain) both animals developed renewed paralysis. However, whereas paralysis in one monkey was generalized, involving the arms as well as the legs, the other animal became paralyzed only in the arms, the healthy leg remaining unaffected.

At the time these observations were made it was thought conceivable that repeated intravenous injections of massive doses of virus might serve as a means to transmit poliomyelitis virus directly from the monkey to mice and guinea pigs. Several experiments, however, in which this method was used in an effort to acclimatize the RMV and Ayrcock strains of monkey poliomyelitis virus to mice and guinea pigs led to negative results.

(b) *Pathogenicity for Rabbits*—One of the outstanding characteristics of the murine virus, at the time of its isolation, was its complete lack of pathogenicity for rabbits. It therefore seemed of interest to reexamine murine virus from remote mouse passages for its capacity to induce paralysis in rabbits.

Five rabbits (1500 gm. weight) were injected intracerebrally with 0.4 cc. of a 10 per cent mouse brain suspension (70th to 100th mouse passage). During a period of careful observation, extending over 3 weeks, none of these animals showed any signs of disease.

The experience of the foregoing experiments may be summarized by saying that prolonged passage of murine virus through mice apparently is associated with an appreciable change in biological properties. This change manifests itself chiefly in an increased potency for mice and, at the same time, in a broader range of virulence for other rodent hosts<sup>1</sup>. The original lack of pathogenicity for rabbits, on the other hand, remained entirely unaffected. As far as its pathogenic power for *rhesus* monkeys is concerned, continued mouse passage seems to have brought about a better ability of murine virus to localize in the central nervous system, particularly the brain, of monkeys following intracerebral injection. The fact that repeated peripheral introduction of massive doses of virus may cause, on occasion, typical flaccid paralysis must also be recognized. The murine virus, therefore although incapable of producing regularly typical poliomyelitis, must still be regarded as an infectious agent with limited pathogenic properties for the *rhesus* monkey.

<sup>1</sup> It may be mentioned in this connection that murine virus harvested from remote mouse passages produced flaccid paralysis in 7 of 12 albino rats.

*Age Resistance of Mice to Infection with Murine Virus*

The influence of age on the susceptibility of mice to infection with various neurotropic viruses has been made the subject of recent extensive investigations. The sum total of this work indicates that there develops in growing mice a well marked resistance to peripheral infection which can clearly be demonstrated with such viruses as equine encephalomyelitis (6), vesicular stomatitis (7), and rabies (8), in no case could any difference be detected between young and old mice in their susceptibility to intracerebral injection of virus. It was therefore suggested that the resistance acquired with age in animals which had experienced no previous immunizing contact with the infectious agent is caused by the development and perfection of physiological barriers which serve to arrest centripetal progression of the virus from a peripheral point of injection. The virus of "spontaneous mouse encephalomyelitis" appears to be quite different in this respect since an increased resistance with age is demonstrable in mice irrespective of whether virus is introduced by the intracerebral or the intranasal route (9). This difference is probably due to the fact that the protective mechanism against Theiler's virus represents a specific form of latent immunity which is acquired by previous contact with the particular virus.

Owing to the absence of susceptible small laboratory animals it has heretofore been impossible to study age resistance to poliomyelitis virus by suitable experimental methods, it was therefore decided to investigate this problem in mice infected with murine virus. Swiss mice, representing three different age groups, according to weight, received graded doses of murine virus by intracerebral injection or by various peripheral routes, including intraperitoneal, intranasal, and oral injections. The incidence of paralysis and the average incubation period are given in Table I.

It will be seen from Table I that no appreciable difference exists in the response of the three age groups of mice to intracerebral injection of murine virus as measured by the incidence of paralysis and the average length of the incubation period. The disease thus produced was fatal with remarkable uniformity in all animals. However, when the results of peripheral infection of virus are compared between the oldest group of mice and the two younger groups a marked difference in susceptibility becomes readily apparent. Thus, whereas the incidence of paralysis among the youngest and the intermediate groups, throughout the entire range of virus dilutions, remained at 100 per cent, or close to 100 per cent, for all three peripheral routes (intraperitoneal, intranasal, feeding), the percentage of paralyzed mice in the oldest age group dropped sharply with each successive dilution of virus, in fact, almost half of all older mice survived peripheral infection with the smallest amounts of virus without showing any symptoms of the disease. The above data therefore indicate that the central nervous system of old mice remains fully suscepti-

ble to infection with murine virus but that the advance in age is associated with the development of a relative resistance to peripheral infection which seems to operate best when virus is introduced by the nasal route

For the second part of this experiment it seemed of interest to determine whether old mice, which had survived infection by various peripheral routes, possessed any increased resistance towards peripheral reinfection with doses of virus large enough to paralyze all normal control animals of similar age. Ac

TABLE I

*Infection with Murine Virus by Various Routes in Mice of Different Age Groups*

Route of infection	Virus dilution	12-15 gm. mice			20-25 gm. mice			30 gm. (and over) mice		
		No. of mice	Paralysis	Incubation period	No. of mice	Paralysis	Incubation period	No. of mice	Paralysis	Incubation period
			per cent	days		per cent	days		per cent	days
Intracerebral	10 <sup>-4</sup>	70	100	2-3	30	100	2-3	42	100	2-4
	10 <sup>-6</sup>	402*	100	2-3	30	100	2-4	36	100	2-5
	10 <sup>-7</sup>	16	100	2-3	30	100	2-4	47	100	2-5
	10 <sup>-8</sup>	16	100	3-4	10	100	3-4	39	92 7	3-5
Intraperitoneal	10 <sup>-2</sup>	23	100	3-4	811*	100	3-4	62	100	4
	10 <sup>-3</sup>	56	100	3-4	196*	100	3-5	65	98 4	4-7
	10 <sup>-4</sup>	59	100	3-4	85	100	3-5	179*	74 4	4-7
	10 <sup>-5</sup>	12	100	3-4	67	100	4-6	25	68	5-7
	10 <sup>-6</sup>	10	100	4-5	30	100	4-6	25	60	5-7
Intranasal	10 <sup>-2</sup>	12	100	3-5	10	100	3-6	25	48	4-7
	10 <sup>-3</sup>	8	100	3-5	10	100	4-7	21	66 7	5-7
	10 <sup>-4</sup>	12	92	4-6	10	70	4-7	15	40	5-7
Feeding (by gavage)	10 <sup>-4</sup>	16	81 2	3-5	10	90	4-6	15	60	4-7

\* Unusually large numbers of mice were available in these instances, since the brains of these animals were used for the preparation of immune sera, as described later in this paper

cordingly, a total of 42 old mice surviving from primary infection by either intraperitoneal, nasal, or gastrointestinal routes, were reinfected intraperitoneally with 0.1 cc. of 10<sup>-2</sup> or 10<sup>-3</sup> dilution of murine virus, these amounts of virus, in our experience, have never failed to paralyze old mice (see Table I). In this group of 42 reinfected old mice, only 2 mice developed paralysis, whereas 40 mice remained free from any symptoms of disease. The results of this experiment, therefore, indicate that symptomless murine infection induced in old mice, by subeffective doses of virus, is followed by the development of a strong immunity which protects against peripheral reinfection with the same virus.

### *Seasonal Fluctuations in Susceptibility of Mice to Infection with Murine Virus*

As mentioned before, the murine virus, since its isolation, has been maintained by unbroken serial passage from mouse to mouse. These passages were carried out as routine, at the rate of two or three transfers each week, in Swiss mice, weighing from 12 to 15 gm. As a rule, groups of 6 mice were used for each passage, all animals receiving 0.03 cc of a  $10^{-6}$  dilution of virus (mouse brain suspension) by intracerebral injection. Records which extend over a considerable period of time are therefore available for a continuous study of the infectivity of murine virus under standard conditions of infection. The results obtained during the entire year of 1941 have been brought together in Chart 1.

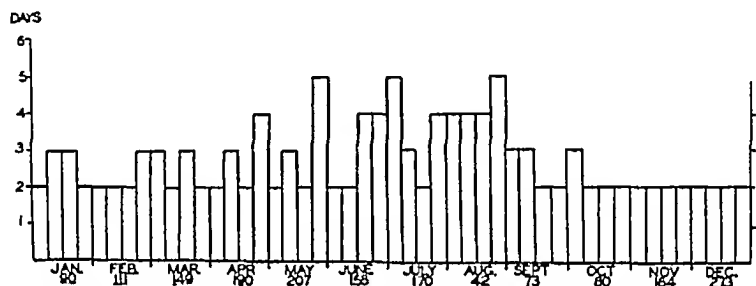


CHART 1 Average incubation period throughout the year 1941 of Swiss mice (12 to 15 gm) following intracerebral infection with a constant dose of 0.03 cc of murine virus in a dilution of  $10^{-6}$ . Each column represents the average incubation period observed in 2 to 3 mouse passages carried out within periods of 6 to 9 days. The figures under each month indicate the total number of mice used during that period.

The data assembled in Chart 1 indicate that the disease was uniformly fatal in all mice, there being no survivors among a total of 1707 animals following injection with the chosen test dose of virus. It will be observed, however, that the average incubation period in mice injected at certain times of the year is subject to marked variation. Thus, whereas the incubation period from January to April and, again, from October to December was regularly between 2 and 3 days, somewhat longer incubation periods were noted between May and September, the most definite prolongations (4 to 5 days) occurring during the summer months of June, July, and August. The reasons for this phenomenon are unknown. To mention only one point, it is not certain whether the observed fluctuations should be ascribed to cyclic variations in virulence of the virus or to seasonal changes in susceptibility of the host, although the latter seems more likely.



*Immunological Studies with the Murine Virus*

(a) *Serological Tests*—Previous experiments (1) had shown that inactivation of murine virus, in its early mouse passages, may be obtained by *in vitro* contact with various antipoliomyelitis sera. The degree of neutralization demonstrable in these tests was only slight in the case of several convalescent monkey sera, but marked neutralization occurred with one poliomyelitis hyperimmune horse serum. Conversely, neutralization tests carried out with antimurine sera prepared in rabbits or monkeys indicated that some of these sera possessed the power to inactivate the homologous (SK) or related (Aycock) strains of monkey poliomyelitis virus while no neutralizing power could generally be demonstrated against the RMV virus. To be precise, of a total of 24 antimurine sera tested against SK or Aycock virus, inactivation of either virus occurred with exactly one-half, *i.e.* 12 sera, whereas the remaining 12 sera showed no virucidal power. Neutralization was therefore demonstrable, but far from regular in these tests.

In view of the irregular results obtained heretofore it was decided to reinvestigate the serological analysis of SK murine virus with new antisera. The following immune sera were tested in mice for neutralizing activity against murine virus: hyperimmune antimurine horse sera,<sup>2</sup> hyperimmune antimurine and anticavian rabbit sera,<sup>3</sup> sera obtained from monkeys convalescing from infection with SK or Aycock poliomyelitis virus, hyperimmune antipoliomyelitis horse sera,<sup>3</sup> hyperimmune anti lymphocytic-choriomeningitis rabbit serum,<sup>4</sup> and normal mouse, rabbit, horse, and monkey sera. The hyperimmune antimurine horse sera were also tested for neutralizing activity against the RMV and the Aycock strains of poliomyelitis virus in monkeys and a hyperimmune antimurine rabbit serum for neutralizing activity against the WE strain<sup>4</sup> of lymphocytic choriomeningitis virus in mice. Finally, hyperimmune antimurine horse serum and hyperimmune antipoliomyelitis horse serum were tested in mice for neutralizing power against the GD VII strain<sup>5</sup> of Theiler's "spontaneous mouse encephalomyelitis" virus.

The preparation of the hyperimmune antimurine sera will be briefly outlined here.

<sup>2</sup> Acknowledgment is gratefully made to Lederle Laboratories for preparation of these sera and for financial support in connection with this phase of the work.

<sup>3</sup> These sera were obtained through the courtesy of Dr. J. A. Toomey from the City Hospital, Cleveland.

<sup>4</sup> This serum and virus were obtained through the courtesy of Dr. J. E. Smadel from The Rockefeller Institute.

<sup>5</sup> This virus was obtained through the courtesy of Dr. Max Theiler from The Rockefeller Foundation.

Three horses (A2050, A2051, A2052) were subjected to the following course of immunization with murine virus 4 series of injections were administered over a period of 6 months (Feb, 1941, to July, 1941<sup>6</sup>), each series consisting of 4 to 9 injections given at intervals of 2 to 4 days during a 2 to 3 week period. The material used for immunization consisted of a mixture of tissue culture murine virus with 10 per cent mouse brain suspension prepared from paralyzed mice, in a ratio of 3:1 or 2:1. For the first series of injections formalized antigen (0.2 per cent) was used, subsequently untreated antigen was employed. The former was injected in 100 to 200 cc. doses, the latter in doses increasing from 20 cc. to 250 cc. Injections were made by the intravenous, intraperitoneal, and subcutaneous routes, or by combined routes, as was deemed most judicious at the time of each injection. One horse (A2050) died with indefinite symptoms after 16 injections had been given, two horses (A2051, A2052<sup>7</sup>) lived through the entire immunizing period and received approximately 27 injections. After each series of immunizing injections the horses were bled and their sera tested for neutralizing activity.

In addition, three groups of rabbits, each group consisting of 15 animals, were immunized as follows: group A with cavian virus (10 per cent brain and cord suspension from paralyzed guinea pigs), group B with murine virus (10 per cent mouse brain suspensions from paralyzed mice), and group C with tissue culture fluid containing murine virus. The rabbits in groups A and B received an average of 10 to 12 injections, by the intravenous and intraperitoneal routes, in 2 to 3 series of injections. For the first series formalized antigen (0.2 per cent) was injected in 5 to 20 cc. doses, subsequent injections of untreated antigen were given in doses increasing from 2 cc. to 30 cc. Many animals in these two groups died from shock during immunization. The rabbits in group C were treated similarly, except that larger doses of antigen were used, the animals receiving an average of 12 to 18 injections (10 to 50 cc. in the first, 5 to 100 cc. in the second and third series of injections). This material was well tolerated and there were no losses in this group. All surviving animals were bled after each series of injections, the sera pooled according to origin and tested for neutralizing activity.

The results obtained with the various immune sera used for this serological study are brought together in Tables II to VIII. An examination of the data presented shows that the immunization of horses with murine virus led to the development in the serum of a very high virucidal titer against this virus (Tables II and III). Similarly, antisera produced by the immunization of rabbits with either murine or cavian virus were capable of inactivating large

<sup>6</sup> During this time these animals also received, as routine preventative measures, two injections of equine encephalomyelitis chick vaccine and tetanus toxoid.

<sup>7</sup> It should be mentioned that one horse (A2052), 9 days after termination of the last series of murine virus injections, showed stumbling of the front legs. One week later progressive flaccid paralysis of the posterior quarters was noted. The next day this paralysis was complete and the animal was destroyed. No virus pathogenic for mice, guinea pigs, or monkeys could be recovered from the brain or cord. The cause of the paralysis in this horse was unknown.

amounts of murine virus. On the other hand, a hyperimmune serum against the virus of lymphocytic choriomeningitis was as completely devoid of neu-

TABLE II

*Titration in Mice of Successive Trial Bleedings Obtained from Horses under Immunization with Murine Virus against a Constant Test Dose ( $10^{-6}$ ) of Murine Virus*

Serum	Virus dilution	Serum dilutions					
		Un-diluted	1:10	1:20	1:50	1:100	1:500
Horse A2050							
1st trial bleeding	$10^{-3}$	0/3	2/3	3/3	2/3	3/3	
2nd "	$10^{-3}$	0/3	0/3	2/3	2/3	3/3	
3rd "	$10^{-3}$	0/3	0/3	0/3	1/3	1/3	
Horse A2051							
1st trial bleeding	$10^{-3}$	1/3	2/3	3/3	3/3	3/3	
2nd " "	$10^{-3}$	0/3	0/3	1/3	0/3	1/3	
3rd "	$10^{-3}$	0/6	0/3	0/3	0/6	0/6	0/3
4th "	$10^{-3}$	1/3			0/3	0/3	1/3
Horse A2052							
1st trial bleeding	$10^{-3}$	0/3	1/3	1/3	3/3	3/3	
2nd "	$10^{-3}$	0/3	1/3	0/3	2/3	1/3	
3rd "	$10^{-3}$	1/6	0/3	0/3	0/6	1/6	0/3
4th "	$10^{-3}$	0/3			0/3	0/3	0/3
5th "	$10^{-3}$	0/7	1/4		2/7	1/7	3/7
Normal horse serum 1	$10^{-3}$	3/3					
" " "	$10^{-4}$	3/3					
" " "	$10^{-5}$	2/3					
" "	$10^{-6}$	1/3					
Normal horse serum 2	$10^{-3}$	3/3					
" "	$10^{-4}$	3/3					
" "	$10^{-5}$	1/3					
" "	$10^{-6}$	1/3					

Numerator = number of mice paralyzed. Denominator = number of mice injected

*Technique*—In preparing serum-virus mixtures, 0.5 cc. of virus dilution was added to 0.5 cc. of undiluted or diluted serum after incubation for 1 hour at 37°C., 0.2 cc. of each mixture was injected intraperitoneally into each of 3 or more mice. The mice were observed routinely over a period of 10 to 14 days following injection of non neutralizing mixtures paralysis appeared regularly within 3 to 5 days. The same technique was used in all subsequent tests unless otherwise noted.

tralizing power against murine virus as was normal rabbit serum (Table IV). Conversely, lymphocytic choriomeningitis virus was not inactivated by anti-murine serum (Table V). Neutralization tests with Aycock and SK monkey

poliomyelitis-convalescent sera gave irregular results, thus, one each of two Aycock and two SK sera neutralized large amounts of murine virus, but the other Aycock and SK sera had little or no demonstrable virucidal power

TABLE III

*Neutralization in Mice of Variable Doses of Murine Virus by a Constant Amount of Undiluted Hyperimmune Antimurine Horse Serum*

Undiluted serum, trial bleeding after 2 series of injections	Virus dilutions					
	10 <sup>-1</sup>	10 <sup>-2</sup>	10 <sup>-3</sup>	10 <sup>-4</sup>	10 <sup>-5</sup>	10 <sup>-6</sup>
Immune horse serum A2050	2/3	0/3	0/3	1/3	0/3	0/3
" " " A2051	1/3	0/3	0/3	0/3	0/3	0/3
" " " A2052	0/3	1/3	0/3	0/3	0/3	0/3
Normal horse serum 1		3/3	3/3	3/3	2/3	0/3
" " " 2		3/3	3/3	2/3	0/3	0/3
" " " 3		3/3	3/3	3/3	1/3	0/3
" " " 4		3/3	3/3	3/3	1/3	0/3
" " " 5 (phenolized*)		3/3	3/3	3/3	1/3	0/3
" " " 6		3/3	3/3	3/3	3/3	
" " " 7 (tricresolized*)		4/4	4/4	4/4	4/4	

Numerator = number of mice paralyzed. Denominator = number of mice injected.

\* Serum 5 represents serum 4 to which sufficient phenol has been added to make a final concentration of 0.5 per cent, serum 7 represents serum 6 to which sufficient tricresol has been added to make a final concentration of 0.3 per cent.

TABLE IV

*Neutralization Tests in Mice with Murine Virus against Hyperimmune Anti Murine-, Anti Canian-, and Anti Lymphocytic Choriomeningitis Virus Rabbit Sera*

Undiluted serum	Virus dilutions				
	10 <sup>-1</sup>	10 <sup>-2</sup>	10 <sup>-3</sup>	10 <sup>-4</sup>	10 <sup>-5</sup>
Antimurine rabbit serum	0/3	1/3	0/3	0/3	
Anticavian rabbit serum	0/3	0/3	0/3	0/3	
Anti lymphocytic-choriomeningitis rabbit serum	6/6	6/6	5/6	4/6	
Normal rabbit serum		5/6	4/6	2/6	1/6

Numerator = number of mice paralyzed Denominator = number of mice injected

(Table VI) The irregularity of these results renders their interpretation difficult, particularly since none of these sera had been tested for their ability to neutralize corresponding strains of poliomyelitis virus in the monkey. It will also be observed that the second Aycock serum, when run against an early passage of murine virus, failed to give clear-cut neutralization (Table VI). More reliable results were obtained with a potent hyperimmune poliomyelitis

horse serum (pseudoglobulin fraction)<sup>8</sup> which proved capable, in repeated tests, of inactivating comparatively large amounts of murine virus, the unrefined serum, on the other hand, possessed little or no neutralizing power (Table VII). Normal sera from various species of animals showed no neutralizing effect on murine virus, including sera obtained from normal adult mice and cotton rats (Table VII). By contrast, the same samples of adult normal mouse serum brought about complete inactivation of Theiler's virus (Table VIII). As far as

TABLE V

*Neutralization Tests in Mice with Lymphocytic Choriomeningitis Virus against Hyperimmune Anti Lymphocytic-Choriomeningitis Serum and Hyperimmune Antimurine Rabbit Serum*

Serum	Virus dilutions	Days									
		6th	7th	8th	9th	10th	11th	12th	13th	14th	
Hyperimmune anti lymphocytic-choriomeningitis rabbit serum	10 <sup>-2</sup>	---	---	---	---	---	---	---	---	---	
	10 <sup>-4</sup>	---	---	---	---	---	---	---	---	---	
	10 <sup>-6</sup>	---	---	---	---	---	---	---	---	---	
Hyperimmune antimurine rabbit serum	10 <sup>-2</sup>	- + ±	- ++ ±	- D ±	++	++	++	D +	D		
	10 <sup>-4</sup>	- + +	- D ++	- D	±	±	±	+	D		
	10 <sup>-6</sup>	± + ++	++ ++	D D ++	D						

- = no symptoms. ++ = marked symptoms.

± = beginning illness. D = dead.

+ = ill.

*Technique.*—0.5 cc. of undiluted serum was combined with 0.5 cc. of virus dilution to give the final dilutions indicated in the table. Mixtures were held for 1 hour at 37°C. and 2 hours at room temperature. 0.03 cc. of each mixture was injected intracerebrally into each of 3 mice.

the neutralization of Theiler's virus by antimurine horse serum is concerned, it appears that this virus was definitely neutralized by antimurine horse serum.

<sup>8</sup> According to information received from Dr. Toomey, this particular serum contained 0.5 per cent phenol. Marked neutralization had previously been obtained with the pseudoglobulin fraction of another antipoliomyelitis horse serum (1). As far as could be ascertained at that time the latter serum was free from any preservative, it has since become heavily contaminated, thus precluding its further use. The question has been raised (10) whether the presence in serum of a preservative, such as phenol in proper concentration might serve to bring about spurious inactivation of murine virus by chemical action. To answer this question samples of normal horse serum were phenolized (0.5 per cent concentration) or tricresolized (0.3 per cent concentration) and compared for virucidal action with the untreated samples. The results of this experiment are given in Table III. They show that the addition of such preservatives had in no way altered the inability of normal serum to inactivate murine virus. Intracerebral injection of such serum virus mixtures into mice likewise failed to result in virus inactivation.

up to a titer of 1 50 serum dilution, as contrasted with a titer of approximately 1 500 serum dilution against a comparable dose of murine virus. It is further evident that some neutralization of Theiler's virus occurred with potent antipoliomyelitis horse serum though such neutralization was in no way comparable with the marked neutralizing action of the same serum on SK murine virus. As far as the neutralization of monkey poliomyelitis virus is concerned, it was found that neither antimurine horse sera nor antimurine or anticavian rabbit sera possessed any demonstrable inactivating power against the SK, Aycock, or RMV virus as determined by intracerebral tests in mon-

TABLE VI

*Neutralization Tests in Mice with Murine Virus of Remote or Early Mouse Passages against Poliomyelitis-Convalescent Monkey Sera*

Undiluted serum	Murine virus used	Virus dilutions						
		10 <sup>-2</sup>	10 <sup>-3</sup>	10 <sup>-4</sup>	10 <sup>-4</sup> †	10 <sup>-5</sup>	10 <sup>-5</sup> ‡	10 <sup>-6</sup>
Aycock convalescent serum 1	179th-223rd mouse passage	0/3	0/3	0/3		0/3		
" " " 2		3/3	6/6	6/6		4/6		0/3
SK convalescent serum 1	" "	0/3	0/3	0/3		0/3		
" " " 2		6/6	6/6	6/6		6/6		
Normal monkey serum 1	" "		3/3	3/3		3/3		3/3
" " " 2			3/3	3/3		3/3		3/3
Aycock convalescent serum 2	16th mouse passage		12/12	12/12	9/12	13/18	6/18	0/6
Normal monkey serum 3	" "		6/6	5/6	5/6	5/9	6/9	2/6

keys. This statement is based on results obtained with a total of 32 monkeys which received immune serum-virus mixtures and 14 accompanying control animals, none of which escaped paralysis.

Since all neutralization tests against murine virus in mice were done by the intraperitoneal route, it is pertinent to mention here that wide discrepancies were found to exist between intraperitoneal and intracerebral injection of similar virus-serum mixtures. Thus, it has been impossible to demonstrate neutralizing activity of antimurine sera against either SK murine virus or against Theiler's virus in mice by the latter route. The reasons for this discrepancy are not yet clear and the problem is undergoing further investigation.

In summary, it may therefore be stated that no serological relationship was demonstrated between SK murine virus and the virus of lymphocytic choriomeningitis. That some serological relationship exists between SK murine

TABLE VII

*Neutralization Tests in Mice with Murine Virus against Hyperimmune Antipoliomyelitis Horse Sera*

Undiluted serum	Virus dilutions				
	10 <sup>-4</sup>	10 <sup>-5</sup>	10 <sup>-6</sup>	10 <sup>-7</sup>	10 <sup>-8</sup>
096464-G	3/3	2/3	1/3	0/3	
097607 A	1/3	1/3	0/3	0/3	
Normal horse serum		3/3	2/3	0/3	0/3
096464-G	3/3	3/3	3/3	3/3	
097607 A	2/3	1/3	0/3	0/3	
Normal monkey serum		3/3	3/3	3/3	3/3
096464-G	3/3	3/3	2/3	0/3	
097607 A	3/3	0/3	0/3	0/3	
Normal monkey serum		3/3	3/3	3/3	3/3
097607 A	3/3	0/3	0/3	0/3	
Normal horse serum		3/3	3/3	2/3	0/3
Adult normal mouse serum	3/3	3/3	3/3	3/3	
097607 A	3/3	0/3	0/3	0/3	
Normal horse serum		3/3	3/3	1/3	1/3
Adult normal mouse serum	3/3	3/3	2/3	2/3	
Adult normal cotton rat serum	3/3	3/3	3/3	3/3	3/3

Numerator = number of mice paralyzed. Denominator = number of mice injected.

\* These sera were obtained through the courtesy of Dr. Toomey. Serum 097607 A is the pseudoglobulin fraction of 096464-G.

TABLE VIII

*Neutralization Tests in Mice with Theller's Virus against Hyperimmune Antimurine Horse Serum, Hyperimmune Antipoliomyelitis Horse Serum, and Adult Normal Mouse Serum*

Serum	Virus dilution	Serum dilutions			
		Un-diluted	1:10	1:50	1:100
Antimurine horse serum	10 <sup>-1</sup>	4/28	0/8	2/8	6/8
Antipoliomyelitis horse serum (097607-A)	10 <sup>-1</sup>	9/16			
Normal adult mouse serum	10 <sup>-1</sup>	2/20			
Normal horse serum	10 <sup>-1</sup>	25/28			

Numerator = number of mice paralyzed. Denominator = number of mice injected.

*Technique.*—2.0 cc. of a 10<sup>-1</sup> dilution of Theller infected mouse brains (strain GD VII) were added to 2.0 cc. of serum after incubation for 1 hour at 37°C. 0.4 cc. of each mixture was injected intraperitoneally into the designated number of mice.

human and monkey sera. Most of these distinguishing features, however, are only relative. Thus, murine as well as cavian SK virus will, on occasion, produce flaccid paralysis in *rhesus* monkeys, the virulence of cavian virus in guinea pigs is not appreciably higher than the virulence level of poliomyelitis virus in monkeys, and specific neutralization *in vitro* of both, cavian and murine virus, is demonstrable with antipoliomyelitis hyperimmune horse sera. It is further significant that Toomey's (12) recent experience with the adaptation of SK monkey virus has been similar to ours in that established rodent strains of this virus do not transfer back to the monkey. On the other hand, the initial monkey pathogenicity of the Lansing strain of murine poliomyelitis virus is apparently lost with long continued mouse passages (13). The actual significance of the existing differences, as a measure of similarity or dissimilarity, is therefore probably more apparent than real. Certainly none of these rodent strains stand sufficiently apart with regard to any of the above mentioned criteria to warrant an assumption that they represent totally unrelated virus entities.

As far as the possibility of confusion with any of the known viruses is concerned, the chances for a mistaken identity appear exceedingly slight. While lymphocytic choriomeningitis virus may occur as a stray virus in stocks of normal rodents, the symptomatology and pathology of either SK murine or SK cavian infection are incompatible with the picture of lymphocytic choriomeningitis. Additional evidence to the contrary comes from the serological data and the dissimilar particle size of the two respective viruses (14). With regard to Theiler's virus of so called "spontaneous mouse encephalomyelitis" the necessity for a careful differential diagnosis becomes more pressing, since the symptomatology, pathology, and epidemiology of that disease, as well as the morphology of its virus, are closely akin to simian and human poliomyelitis. In view of the circumstances it is only possible to single out certain fundamental characteristics in the behavior in mice of Theiler's virus and of SK murine virus which would tend to show whether the two viruses are or are not identical. Since mice are commonly exposed, early in life, to Theiler's virus by virtue of carrying the infectious agent in feces a herd immunity rapidly develops which is sufficiently strong to leave only young animals uniformly susceptible to infection. Even in young mice intracerebral injection of virus succeeds better than peripheral injection, presumably because nerve tissue is slow in participating in the subclinical specific immunity. The local strength of the protective mechanism is also indicated by the inability to infect mice with Theiler's virus from the gastrointestinal route. While older animals can be infected, particularly with certain Theiler passage strains of unusually high virulence, massive doses are usually required to paralyze old mice with any degree of regularity, even when the virus is injected directly into the central nervous system. By comparison, SK murine virus behaves in mice like



any virus which is introduced on virgin soil. Thus, SK murine virus will infect young mice uniformly to a high titer, not only by intracerebral inoculation but by any peripheral route that one may choose. Old mice, when infected peripherally with SK murine virus, exhibit the same type of non-specific age resistance observed with other neurotropic viruses upon propagation in previously unexposed herds or animals, again, in contrast to Theiler's virus, there is no loss of cerebral susceptibility to murine virus with age. As far as the immunological evidence is concerned, antimurine horse serum and, to a lesser extent, concentrated antipoliomyelitis horse serum are found to bring about some inactivation of Theiler's virus, although such inactivation is distinctly inferior to that observed with SK murine virus. While some serological relationship between murine SK and Theiler's virus is therefore undeniable, the fact that normal adult mouse serum has no effect whatsoever on SK murine virus, whereas the same serum completely inactivates Theiler's virus, is of crucial significance in establishing the different origin of the two viruses in question. Some essential difference in the antigenic pattern of the two viruses is furthermore indicated by the results of cross immunity tests which show that Theiler immune mice remain fully susceptible to reinfection with murine SK virus. To the criteria mentioned above must be added the divergent response that certain other animals exhibit to infection with the two viral agents. Thus far the guinea pig and the monkey have proven insusceptible to Theiler's virus. SK murine virus, on the other hand, establishes itself in both monkeys and guinea pigs and is capable of producing paralysis, irregularly in monkeys, and regularly in guinea pigs. The weight of the evidence is therefore in favor of regarding the murine strain of SK virus as a virus etiologically distinct from the known strains of Theiler's virus, even though the overlapping serological immune reactions suggest some genetic relationship between the two infectious agents and, indeed, with monkey poliomyelitis virus itself.

The possibility that the SK murine virus originated as a hitherto unknown virus in cotton rats is strongly contraindicated by the fact that normal adult cotton rat serum is without effect on this virus, in addition, the behavior of SK virus in cotton rats, in all essential respects, is similar to that in mice.

Since both SK murine and SK cavian virus were obtained as the result of continuous passage of SK poliomyelitis virus from the monkey to cotton rats and thence to white mice and guinea pigs, it remains to review the evidence in favor of regarding these rodent viruses as true descendants of poliomyelitis virus. To begin with, in its basic characteristics, such as symptomatology, pathology, and epidemiology, the disease in guinea pigs (5), and to a lesser extent in mice, has much in common with the disease in man or monkey. Moreover, the particle size of cultured murine virus, as determined by ultrafiltration, is similar to that of poliomyelitis virus (14). On the other hand, identification

by serological methods cannot be considered as fully established. While murine virus and cavian virus are both definitely neutralized *in vitro* by concentrated antipoliomyelitis horse sera, unconcentrated antipoliomyelitis horse serum or poliomyelitis-convalescent monkey sera show none or irregular neutralizing power. Likewise, immunization of horses with murine virus leads to the development of a high virucidal titer against both rodent viruses with no demonstrable neutralizing activity against three strains of monkey poliomyelitis virus. These observations therefore indicate the existence of certain quantitative and perhaps qualitative immunochemical differences between monkey poliomyelitis and SK rodent virus which cannot be satisfactorily explained at present.

In summarizing the available data it would seem more rational, at this time, to place the SK murine virus in line with the other rodent strains of poliomyelitis virus and to accept all of them as variants of true poliomyelitis virus rather than to seize upon minor individual differences in an attempt to accord to the SK murine virus an autonomous status as a new virus. While the latter hypothesis is tenable, in principle, one would have to insist on positive corroborative evidence to that effect in order to justify taking such a position.

#### CONCLUSIONS

- 1 SK murine virus maintained over more than 200 serial mouse passages increased in virulence for mice from an initial intracerebral titer of about 1:1 million to a maximum titer of not less than 1:1 billion dilution activity.

- 2 Following intracerebral injection with murine virus of remote mouse passages, 5 of 13 *rhesus* monkeys developed a characteristic encephalitic syndrome. Repeated intravenous injection of massive doses of virus caused localized flaccid paralysis in 2 of 14 monkeys.

- 3 Intracerebral injection of graded doses of murine virus into mice of different age groups caused fatal paralysis in young and old animals alike. Infection with small doses of virus by peripheral routes, while uniformly fatal to young mice, was followed by survival of almost half of the old mice.

- 4 The incubation period of the disease in young mice infected intracerebrally with a standard dose of murine virus, when studied throughout the period of 1 year, was found considerably lengthened during the summer months.

- 5 Cross neutralization tests furnished no evidence for any serological relationship between SK murine virus and lymphocytic choriomeningitis virus. Theiler's virus was found to be neutralizable by antimurine horse serum and, to a lesser extent, by concentrated antipoliomyelitis horse serum, however, such inactivation, in both cases, was distinctly inferior to that occurring with SK murine virus. On the other hand, no neutralization whatsoever was obtained between SK murine virus and normal adult mouse serum, whereas the same serum completely neutralized Theiler's virus. Mice surviving

infection with Theiler's virus, though acquiring immunity to this virus, remained fully susceptible to reinfection with SK murine virus

6 Neutralization tests with SK murine virus against poliomyelitis-convalescent monkey sera gave irregular results, but neutralization of murine virus occurred regularly with a hyperimmune antipoliomyelitis horse serum. Hyperimmune antimurine horse and rabbit sera, on the other hand, failed to inactivate three strains of monkey poliomyelitis virus (SK, RMV, Aycok) by intracerebral tests in monkeys. The same sera inactivated murine virus in mice by intraperitoneal, but not by intracerebral injection of virus-serum mixtures.

7 The identity of SK murine virus and its relation to other rodent strains of poliomyelitis virus is discussed on the basis of the available data.

#### BIBLIOGRAPHY

- 1 Jungeblut, C. W. and Sanders, M., *J. Exp. Med.*, 1940, **72**, 407
- 2 Armstrong, C., *Pub. Health Rep., U. S. P. H. S.*, 1939, **54**, 1719
- 3 Toomey, J. A., and Takacs, W. S., *Proc. Soc. Exp. Biol. and Med.* 1940, **45**, 364, 1941, **48**, 22, 319
- 4 Jungeblut, C. W., and Sanders, M., *J. Am. Med. Assn.*, 1941, **118**, 2136
- 5 Jungeblut, C. W., Feiner, R. R., and Sanders, M., *J. Exp. Med.*, 1942, **78**, in press.
- 6 Olitsky, P. K., Cox, H. R., and Syverton, J. T., *J. Exp. Med.*, 1934, **59**, 159  
Olitsky, P. K., Sabin, A. B., and Cox, H. R., *J. Exp. Med.* 1936, **64**, 723  
Sabin, A. B., and Olitsky, P. K., *Proc. Soc. Exp. Biol. and Med.*, 1938, **38**, 595, 597  
Morgan, I., *J. Exp. Med.* 1941, **74**, 115
- 7 Sabin, A. B., and Olitsky, P. K., *J. Exp. Med.*, 1937, **68**, 15, 35
- 8 Casals, J., *J. Exp. Med.* 1940, **72**, 445, 453
- 9 Theiler, M., and Gard, S., *J. Exp. Med.* 1940, **72**, 49
- 10 Armstrong, C., *Harvey Lectures*, 1941, **38**, 39
- 11 Toomey, J. A., and Takacs, W. S., *Proc. Soc. Exp. Biol. and Med.* 1941, **47**, 123
- 12 Toomey, J. A., and Takacs, W. S., *J. Bact.*, 1942, **43**, 87
- 13 Theiler, M., *Medicine* 1941, **20**, 443
- 14 Sanders, M., and Jungeblut, C. W., *J. Exp. Med.*, 1942, **75**, 631



## STUDIES IN RODENT POLIOMYELITIS

### II CULTIVATION OF THE MURINE STRAIN OF SK POLIOMYELITIS VIRUS\*

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Following isolation of a mouse-paralyzing agent by passage of the New Haven (SK) monkey poliomyelitis virus through cotton rats to white mice the successful cultivation *in vitro* of this virus was described (1). The initial studies of the culture virus were, of necessity, limited to an investigation of the basic conditions which permitted serial subcultivation. It appeared from this work that the murine virus grew well in embryonic mouse brain serum ultra filtrate cultures at 37°C, and that the infectious agent could be effectively subcultured by transfer of the supernatant fluid at 3 day intervals.

The present communication deals with the results of uninterrupted maintenance of the mouse virus through 200 successive culture generations. This work includes observations on the importance on virus growth of cellular components in tissue culture, the effect of pH on virus propagation and viability *in vitro*, the rate of propagation of the virus in tissue culture, and, the effect of prolonged cultivation *in vitro* on the infectious properties of the virus. In addition to studying the conditions underlying virus propagation *in vitro*, certain properties of the cultured virus were also investigated. Thus, the size of the murine tissue culture virus was determined by ultrafiltration, the specificity of the cultured murine virus was studied with special reference to any relationship that might exist between lymphocytic choriomeningitis virus and murine poliomyelitis virus, and, finally, an effort was made to determine whether the culture virus could be used in interference experiments to block poliomyelitis virus in monkeys with the same measure of success which had attended similar previous experiments in which mouse passage virus was employed.

#### *The Importance on Virus Growth of Cellular Components in Tissue Culture*

The same type of fluid tissue culture, i. e. minced tissue suspended in ox serum ultrafiltrate,<sup>1</sup> as had been previously found successful for the propaga-

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<sup>1</sup> Grateful acknowledgment is made of support received from the Warner Institute for Therapeutic Research for supplying us with ox serum ultrafiltrate and other materials incidental to this work.

tion of several other viruses (2), was employed throughout this work. Since details of the method have already been published (2, 3), it is only necessary to emphasize here that such culture media, carefully prepared according to directions, provide a stable, physiological environment for the maintenance of viable cells and for the production of high levels of virus potency.

In previous experiments an attempt had been made to determine which cells would provide the best substrate for propagation of the virus. When three different types of tissue were used, *i.e.* embryonic mouse brain, embryonic guinea pig brain, or whole chick embryo, the titers of the different preparations in the 6th culture generation were  $10^{-8}$ ,  $10^{-4}$ , and  $10^{-1}$ , respectively.<sup>2</sup> Embryonic mouse brain was therefore adopted as the routine medium for all subsequent work. Further confirmation of the earlier finding that chick tissue is an unsuitable medium for murine virus growth was obtained as the result of our failure, on six different occasions, to recover active virus from inoculated chorioallantoic membranes. At no time could virus be demonstrated beyond the 2nd egg passage. When virus was present in earlier passages the infectivity of individual tissues did not differ from that of the chorioallantoic membrane.

On the basis of the above findings it appeared that the murine virus represented an agent with decided predilection for the tissues of its most susceptible host, *i.e.* the white mouse. The question arose whether such predilection was broad enough to embrace all mouse tissues or whether a special affinity could be demonstrated between virus growth and nervous tissue, which is the site of the essential lesion in the paralyzed mouse.

In an effort to clarify this point, a tissue culture medium consisting of whole mouse embryo from which the brain had been removed was inoculated with murine virus of the 119th mouse passage. At the same time a routine medium containing embryonic mouse brain substrate was inoculated with the same virus. These cultures were run in parallel series and transferred every 3 or 4 days on the same type of media. Titrations of the 19th subcultures gave titers of  $10^{-5}$  for the whole mouse embryo culture minus brain, and of  $10^{-6}$  in the case of the routine media. On repeating titrations with the 26th subcultures, the titers were  $10^{-4}$  and  $10^{-6}$ , respectively. A comparison of the rate of virus propagation in the two media showed that the titer in the series with whole mouse embryo, minus brain, on the 5th day was 1:10, on the 6th day 1:10,000, and that a titer of 1:100,000 was not attained until the 7th day. By contrast the titer of the embryonic mouse brain culture reached 1:10,000 in 4 days, and in 5 days the maximum level of 1:1,000,000 was obtained.

<sup>2</sup> These particular titers had been established with a dilution technique in which serial dilutions were made with a single pipette. In all subsequent titrations separate pipettes were employed. With the latter technique no titers higher than  $10^{-6}$  were observed.

While the difference in final culture titers was therefore not too impressive, a suggestive retardation in the growth of virus in cultures which contained no mouse brain was readily recognizable in these experiments

Since not all central nervous system tissue had been eliminated from the whole embryo mouse cultures, the possibility was considered that small amounts of remaining spinal cord tissue might account for the relatively good yields of active virus in these cultures. Therefore, at the 26th subculture the virus was transplanted to cultures which contained whole mouse embryo but neither brain nor spinal cord. After eleven serial passages in this type of medium the culture titrated  $10^{-4}$  as compared to  $10^{-4}$  dilution activity for the routine embryonic mouse brain preparations.

It would thus appear that in the absence of central nervous system tissue in cultures, virus potency is definitely reduced, but not abolished. Evidently non nervous embryonic mouse tissue is capable, to some extent, of maintaining a certain basic level of virus growth.

#### *The Effect of pH on Virus Propagation and Virus Viability*

In evaluating the influence of a single environmental factor upon virus propagation *in vitro*, other variables must, of course, be controlled. Thus, in studying the relationship between pH of culture and virus growth all other conditions relating to type of tissue media, and air space were kept uniform. The cultures, therefore, consisted of rubber-stoppered 50 cc. Erlenmeyer flasks, with 10 cc. of serum ultrafiltrate, and enough embryonic mouse brain substrate to make a tissue-fluid ratio of about 1:300. The first test endeavored to show what effect slight pH changes would have on virus growth.

The data (Table I) suggest that a pH adjustment<sup>3</sup> within a comparatively narrow range is followed by only a small (tenfold) reduction in virus potency. However, it was found that two practices, not uncommon in handling fluid cultures, produce a much more serious effect upon virus growth. Thus, when cotton plugs were substituted for rubber stoppers, the pH rose to about 9, and only traces of virus could be demonstrated. Also, removal of the rubber stopper daily for about 30 seconds, without adjusting the pH after replacing the stopper, caused an appreciable decrease in virus harvest.

As a result of this experience, the pH of all cultures is now adjusted as routine at the time the culture is made and thereafter whenever it becomes necessary to open the flasks. 5 per cent  $\text{CO}_2$  is used for this adjustment, since the method is convenient and leads to no extreme pH changes. The effect of a controlled pH is well reflected in a comparison of titers of adjusted and non-adjusted cultures. When early, non-adjusted culture generations (79th, 80th, 84th, and 87th) were tested in mice, potencies of  $10^{-4}$  were obtained,

<sup>3</sup> All pH determinations were made by the Beckman potentiometer

following the institution of routine CO<sub>2</sub> adjustment, however, potencies of 10<sup>-6</sup> were routinely found (97th, 98th, 103rd, and 113th culture generations) It may be noted that the pH of non-adjusted cultures is approximately 7.8 to 8.0, whereas after the introduction of CO<sub>2</sub> the pH lies between 7.4 and 7.6

Following these preliminary tests the next experiments were planned to investigate the influence of drastic changes in pH on the murine virus while it was actively growing, as well as on virus contained in a cell-free medium

TABLE I  
*Effect upon Virus Potency of Varying the pH of Tissue Cultures\**

Culture adjusted with	pH at time of testing	Virus potency by mouse test
Air-CO <sub>2</sub> mixture (1 per cent)	7.8	10 <sup>-5</sup>
" " " (5 " " )	7.4	10 <sup>-6</sup>
" " " (5 " " saturated)	7.2	10 <sup>-6</sup>
Non adjusted	7.8	10 <sup>-6</sup>
Rubber stoppered culture opened daily (non adjusted)	8.2	10 <sup>-4</sup>
Cotton-plugged culture (non adjusted)	9.19	10 <sup>-0</sup>

\* Cultures inoculated with 97th culture generation and incubated for 3 days at 37°C

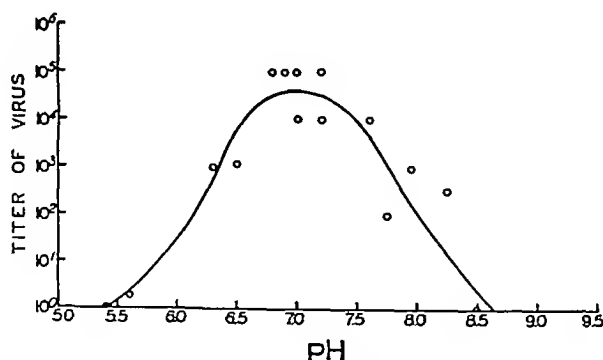


CHART 1 Relationship between pH and infectivity of murine culture virus in cell-free suspension

In the first experiment, virus inactivation at various points of pH was studied while the virus was actively growing in the presence of living cells. Accordingly, a series of 50 cc Erlenmeyer flasks containing the usual amount of embryonic mouse brain was seeded with 0.5 cc of the 140th generation of culture virus. After receiving the virus inoculum, the freshly made cultures were adjusted to varying pH levels in the manner described and incubated for 3 days at 37°C. At the end of that period the infectivity of the cultures was determined by mouse test. The results are recorded in Chart 1. As will be



seen, the relationship between pH and virus infectivity is a simple one. Optimum potency prevails at about pH 7.0. A gradual decline of potency on both sides of the neutral point is easily recognizable, with no definite favoring of either the acid or the alkaline range. This fact was rather surprising since previous experience had shown that the murine passage virus was distinctly acid resistant. It should be noted in this respect, however, that on the earlier occasion HCl had been used as the acidifier, also, that animal passage virus may be better protected by tissue than culture virus.

In the next experiment, a number of routine cultures, after incubation for 3 days at 37°C., were pooled and passed through sterile Reeve Angel No. 226 paper in order to obtain a cell free virus suspension. Uniform volumes of 10 cc.

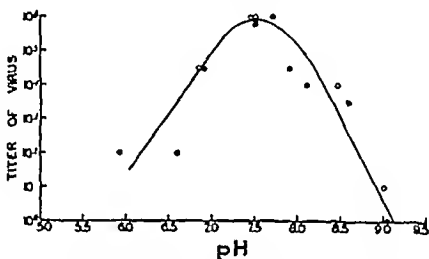


CHART 2 Relationship between pH and infectivity of murine tissue cultures.

of this material were then distributed over a series of 50 cc. Erlenmeyer flasks. The original pH of the pooled cultures was 7.4 and their potency, after paper filtration, titered  $10^{-8}$ . The pH of each 10 cc. sample was then lowered by passing increasing concentrations of  $\text{CO}_2$  through the fluid, alkalization was obtained by decreasing the percentage of  $\text{CO}_2$  or by adding sodium bicarbonate in physiological concentration. All flasks were then placed in the incubator for 3 days. At the end of this period the pH of each flask was again measured with a glass electrode and the virus content determined by mouse test. As may be seen from Chart 2, the relationship between pH and virus infectivity is again a simple one in that a single optimum occurs at pH 7.5 with a gradual decline on both sides of this point. However, a slight shift in the curve to the alkaline side is noticeable.

It is apparent from this study that the optimum range of virus infectivity in tissue culture coincides with the optimum pH for cell viability *in vitro*. When cells were not present, no extreme variation in pH tolerance for the virus could

be detected, as had been noted by Taylor, Sharp, and Beard for the virus of equine encephalomyelitis (4)

*Rate of Propagation of the Murine Virus in Tissue Culture*

Although passage of culture fluid every 3 days and incubation at 37°C had yielded satisfactory titers, it was desirable to determine whether the 3 day period was optimal and, if so, for how long the culture maintained its high level of potency. Flasks containing 10 cc of serum ultrafiltrate and embryonic mouse brain were inoculated with 0.5 cc of culture virus (titer  $10^{-6}$ ), and titrations by mouse test were carried out at various intervals after incubation at 37°C. The data have been brought together in Chart 3. This experiment

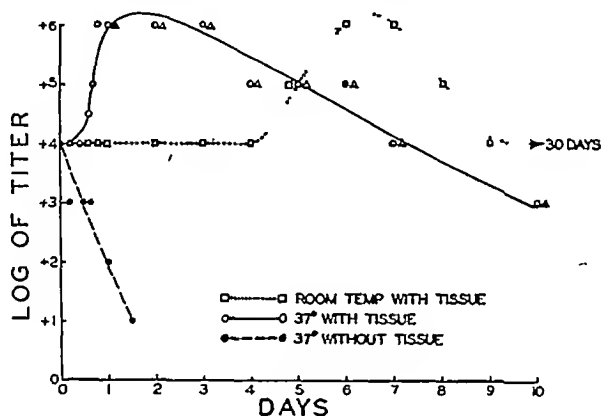


CHART 3 Rate of propagation of the murine virus in tissue culture. Large inoculum (about 17 million mouse-paralyzing doses)

shows that the murine virus propagates at a surprisingly fast rate. As early as 15 hours after inoculation there was an appreciable increase in potency from the point of original dilution activity ( $10^{-4}$ ), and by 19 hours the optimum of  $10^{-6}$  had been reached. This level of infectivity was maintained for about 3 days. Thereafter a gradual decrease in potency occurred so that by the 10th day the culture had dropped to a titer of  $10^{-3}$ . Similar preparations maintained at 37°C, but without cells, showed a rapidly progressive decline in potency, indicating that virus deteriorates quickly under conditions which preclude its growth. When the experiment was repeated at room temperature, results essentially similar to the 37°C curve were obtained, except that the lag period extended to 4 days, this lag period was then followed by a more gradual increase in potency to  $10^{-6}$  on the 6th day. The optimum level was fully maintained for 24 hours with a subsequent gradual decrease to the original point of infectivity on the 9th day. The residual  $10^{-4}$  dilution activity remained unchanged for 30 days.

If one computes the number of mouse-paralyzing doses used as inoculum in the above experiment, an approximate figure of 17 million is reached. Since the optimum dilution activity is only  $10^{-4}$  for the whole culture, comparatively little actual increase of potency seems to have occurred in the culture. A new series of routine cultures was therefore inoculated with virus, but this time a very small dose was used as the inoculum. According to the data in Chart 3, a culture maintained for 4 days at  $37^{\circ}\text{C}$  should have had a dilution activity of 1 100 000. A routine culture was therefore taken from the incubator after 4 days and diluted to that level. Freshly prepared culture media were then inoculated with a volume of 0.5 cc. of this dilution. A titration of

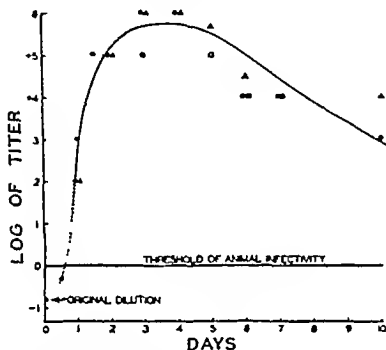


CHART 4 Rate of propagation of the murine virus in tissue culture. Small inoculum (about 1.7 mouse-paralyzing doses)

the source material revealed that the end point dilution had actually been used, in other words, the inoculum in this experiment was approximately 1.7 paralytic mouse doses. Periodic titrations of the incubated cultures ( $37^{\circ}\text{C}$ ) failed to disclose the presence of any virus before 24 hours (Chart 4). Since the original inoculum had been diluted beyond the point of possible infectivity, this finding was not unexpected. In keeping with the slower rate of propagation of minimal doses of virus, the lag period was somewhat longer than when large amounts of virus had been used as seeding material. The optimum level of  $10^{-4}$  was not obtained until the 3rd day, remained at this height for approximately 2 days, and then gradually decreased to  $10^{-3}$  in 10 days. Thus, while the two curves are almost identical from the point of view of contour and levels, there was naturally a much greater objective virus increase in the second experiment than in the first.

*The Effect of Prolonged in Vitro Cultivation on the Infectious Properties of the Murine Virus*

It had been known since the time of its isolation that the cultured murine virus is capable of infecting mice by a diversity of parenteral routes. With an apparently systemic distribution in mice, at least at certain phases of the infection, such a broad power of invasiveness was not surprising. However, since the culture virus was being maintained in a somewhat more restricted environment than the animal passage virus, it seemed desirable to investigate periodically the peripheral infectivity of tissue cultures. The first indication that mouse passage virus and culture virus, after prolonged cultivation, may differ considerably in their ability to infect mice by peripheral routes came in the 49th culture generation when a titration of culture virus by intraperitoneal injection revealed a dilution activity of only  $10^{-3}$ , as compared to a titer of

TABLE II

*Infectivity of Murine Passage Virus and of Murine Culture Virus by Various Routes of Infection*

Route of inoculation	Murine passage virus	Murine culture virus					
		1st generation	2nd generation	49th generation	89th generation	92nd generation	103rd generation
Intracerebral	$10^{-8}$	$10^{-6}$	$10^{-5}$	$10^{-3}$	$10^{-6}$	$10^{-4}$	$10^{-6}$
Intraperitoneal	$10^{-8}$	$10^{-6}$	$10^{-5}$	$10^{-3}$	$10^{-4}$	$10^{-3}$	$10^{-4}$
Intravenous	$10^{-8}$	$10^{-4}$	$10^{-5}$			$10^{-3}$	$10^{-4}$
Intranasal	$10^{-7}$	$10^{-4}$	$10^{-5}$		$10^{-2}$	$10^{-2}$	$10^{-2}$
Subcutaneous	$10^{-7}$	$10^{-6}$	$10^{-5}$			$10^{-3}$	$10^{-3}$

$10^{-6}$  by intracerebral injection. Inasmuch as in earlier tests intracerebral and intraperitoneal titers had been of essentially the same magnitude, it became of interest to determine whether any immediate change would occur when animal virus was placed into tissue culture medium. A brain emulsion of the 108th mouse passage was tested for potency in mice by all possible routes, and 0.5 cc. of the same emulsion was inoculated into tissue culture. As may be seen from Table II, the titer of the mouse passage virus by various routes was approximately the same, *i.e.*  $10^{-7}$  to  $10^{-8}$ , whereas the level of potency of the culture virus in the 1st and 2nd subcultures was uniformly lower for all routes. In short, the change observed with the intraperitoneal titration of the 49th subculture had presumably already occurred somewhere between the 3rd and 49th culture generations. In returning to tissue cultures of more remote passage (89th generation), it was noted that the infectivity for mice by the intranasal route had also dropped. A test of the 92nd subculture revealed the fact that there was a general loss of virulence for all routes except the intracerebral. It appears from these data that the change in the character of the tissue culture virus, which had evidently taken place as the result of

prolonged cultivation *in vitro*, has been a gradual one (Chart 5). It would also seem that the greatest decrease in infectivity has occurred with respect to subcutaneous and intranasal inoculation. Thus the infectivity for mice by the subcutaneous route of the 100th subculture had dropped from an initial titer of  $10^{-4.5}$  to  $10^{-3}$ , as far as intranasal instillation is concerned, the decline in virulence had been equally marked going from an early average of  $10^{-4.5}$  to  $10^{-2}$  in later passages. In comparison herewith the decrease in virulence by intraperitoneal and intravenous routes was much less spectacular (Table II, Chart 5).

Since the persistence of high intracerebral infectivity pointed toward a qualitative rather than a quantitative change in the cultures, further investigation

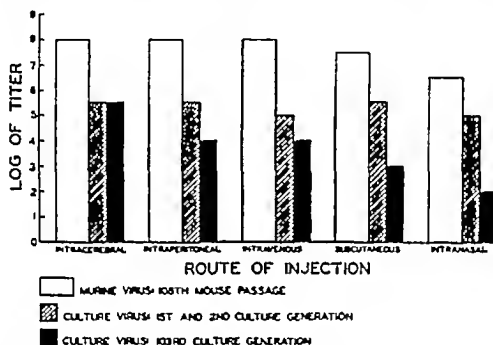


CHART 5 Infectivity of murine passage virus and of murine culture virus by various routes of injection

was undertaken to determine whether a culture, peripherally non infectious, would nevertheless be capable of inducing a state of resistance in mice against subsequent infection with murine passage virus. For this purpose mice were available from earlier tests which had survived the injection by different routes of varying dilutions of the 112th serial culture passage. The surviving mice numbered 104 among a total of 246 animals injected as follows

	No. of mice injected	No. of mice surviving
Subcutaneously	71	22
Intraperitoneally	33	14
Intravenously	60	20
Intranasally	71	42
Feeding	11	6
	246	104

The 104 surviving mice were reinfected with mouse passage virus by the same peripheral routes which had previously been used for injection of the culture virus. The dose of virus was chosen so as to ensure paralysis and death among practically all of the accompanying normal control mice. The results

TABLE III

*Resistance to Reinfection with Murine Passage Virus of Mice Surviving Primary Infection with Tissue Culture Virus*

Route of primary infection with culture virus (112th sub-culture)	Dilution*	Result			Reinfection† of surviving mice with mouse passage virus		Result			Controls‡		
		No of mice injected	Paralyzed	Survived	Route	Dilution*	No of mice injected	Paralyzed	Survived	No of mice injected	Paralyzed	Survived
Subcutaneous	1 10	16	14	2	Subcutaneous	1 100,000	2	0	2	4	4	0
	1 100	30	22	8		1 100,000	8	0	8			
	1 1,000	11	9	2		1 100,000	2	1	1			
	1 10,000	12	2	10		1 100,000	10	2	8			
Intraperitoneal	1 1,000	25	13	12	Intraperitoneal	1 100,000	12	0	12	4	4	0
	1 10,000	8	6	2		1 100,000	2	0	2			
Intravenous	1 100	24	18	6	Intravenous	1 100,000	6	0	6	4	4	0
	1 1,000	18	12	6		1 100,000	6	0	6			
	1 10,000	18	10	8		1 100,000	8	2	6			
Intranasal	Undiluted	8	6	2	Intranasal	1 1,000	2	0	2	4	4	0
	1 10	25	7	18		1 1,000	18	2	16			
	1 100	20	10	10		1 1,000	10	5	5			
	1 1,000	18	6	12		1 1,000	12	4	8			
Feeding by gavage	Undiluted	11	5	6	Feeding by gavage	1 100	6	0	6	4	3	1
Totals							104	18	86	20	19	1

\* The dose was 0.1 cc. for all routes except the intranasal in which 0.05 cc. was instilled.

† Reinfection of animals was carried out 2 weeks after inoculation with tissue culture virus.

‡ Control mice were injected with murine animal passage virus.

of this experiment are given in Table III. It will be noted that of a total of 104 "immunized" mice, 86 proved insusceptible to reinfection with doses of murine passage virus that paralyzed 19 of 20 normal animals. The real difference between immunized and control mice is probably even more significant, because the fatality in the reinfected survivors was highest in those groups of animals which originally had received the smallest amount of tissue culture virus. It would therefore seem that a direct correlation exists between the

size of the antigenic dose and the degree of resistance to subsequent reinfection, in that mice which had received the larger doses of tissue culture virus showed the best protection against reinfection with highly virulent murine passage virus.

#### *Ultrafiltration Experiments with the Murine Tissue Culture Virus*

Inasmuch as nothing was known about the size of the murine virus, beyond the fact that the infectious agent passes readily through a Berkefeld W candle, it became of interest to determine the particle size of the virus by ultrafiltration. The clear supernatant fluid of virus tissue cultures suggested itself as a convenient substrate for this work, since its freedom from particulate matter obviated the necessity for preliminary purification. Moreover, by all accepted standards, the culture virus could be regarded as identical with the mouse passage virus.

The cultures were subjected to light centrifugation at about 3000 r.p.m. for 15 minutes before filtration. End points of filtrability were determined by passing the centrifuged material through a series of graded collodion membranes made in accordance with the technique introduced by Bauer and Hughes (5) for the preparation of modified Elford membranes. Filtration was carried out under positive pressure of 107 cm. mercury. During the entire process the filtrates were protected from light and were kept on ice. Precautions against bacterial contamination were observed in so far as possible. The filtrates were then injected intracerebrally into mice and the symptoms noted. When flaccid paralysis and death resulted the specimen was considered unquestionably positive, if indeterminate symptoms such as rough coat and awkward movements preceded death, in the absence of flaccid paralysis, the filtrate was taken as doubtful from the viewpoint of virus content. In cases in which neither symptoms nor deaths occurred in the injected mice it was assumed that the particular membranes had completely retained the virus. The results of these experiments are given in Table IV.<sup>4</sup>

From Table IV it would appear that the virus passes without difficulty through membranes with an A.P.D. of 30  $\mu$ . On one occasion a positive test was obtained with a 27  $\mu$  membrane. Inasmuch as some mice died when injected with filtrates from membranes measuring down to 25  $\mu$ , it is possible that small amounts of virus passed through pores averaging less than 30  $\mu$  in diameter. However, within the 25 to 27  $\mu$  range no clear-cut paralysis was noted and it remains open to question whether the observed deaths were due to virus activity. Assuming therefore that 30  $\mu$  represents the indisputable end point of filtration, the particle size of the SK murine virus may be placed between 10 and 15  $\mu$ . This calculation is based upon Elford's formula

<sup>4</sup> We are indebted to Mr. Engle Devendorf, formerly of this Department, for preparing the membranes and carrying out the filtration.

which computes the ultrafiltration measurement of viruses as being equal to one-third to one-half the diameter of the largest retaining pore. If the murine virus is compared in size with other viruses of known particle size, it is obvious that there is no room for any possible mistaken identity with the virus of lymphocytic choriomeningitis. Of the remaining viruses which have been measured only that of Theiler's spontaneous mouse encephalomyelitis and that of monkey poliomyelitis have particle sizes corresponding with that of murine poliomyelitis virus.

TABLE IV

*Ultrafiltration of SK Murine Poliomyelitis Virus through Graded Collodion Membranes*

Average pore diameter of membranes	Intracerebral injection of filtrates into mice		
	Positive paralysis and death	Doubtful death with questionable symptoms	Negative: no deaths nor symptoms
<i>mμ</i>			
39	4/4		
34	3/3		
30	3/3		
30	4/4		
30			0/4
27 (3-4 hrs.)	5/5		
27 (overnight)			0/4
27		2/3	
27		2/3	
27			0/4
25		1/4	
20		5/5	
20			0/4
20			0/4
20			0/4
20			0/4
11			0/4

Numerator equals number of mice affected, denominator equals the number of mice injected

*Virus Specificity Illustrated by a Comparison of Murine Poliomyelitis Virus with Lymphocytic Choriomeningitis Virus in Tissue Cultures*

On first consideration there seems little reason for suspecting any relationship between murine poliomyelitis virus and lymphocytic choriomeningitis virus. With the murine virus the incubation period is extremely short, sometimes as little as 24 hours, and the cardinal clinical symptom is flaccid paralysis. By contrast, lymphocytic choriomeningitis virus has an average incubation period of 6 to 8 days and produces in mice a syndrome of hypersensitivity and convulsions which becomes most apparent on sensory stimulation. In other



words, poliomyelitic infection is essentially referable to a lower motor neuron involvement, while the localization of lymphocytic choriomeningitis virus is preponderantly in the brain itself. However, some diversity among various strains of lymphocytic choriomeningitis virus and their widespread presence in natural hosts serve to emphasize the necessity for a strict comparison between the properties of these two viruses.

Apart from what has been said, there are other reasons which prompted this investigation. To begin with, the symptoms produced by lymphocytic choriomeningitis virus may, on occasion, range from the classical syndrome previously described to the occurrence of spastic or flaccid paralysis. Second, the guinea pig is susceptible to this virus and the same species, under certain conditions, may also be infected with the murine poliomyelitis virus (6). Third, lymphocytic choriomeningitis is not only an intercurrent disease in laboratory animals, but may also figure as an occasional contaminant in tissue cultures (7). Finally, there is some evidence (8) that lymphocytic choriomeningitis virus, when grown in tissue culture, may undergo a change so that the virus, after extended subcultivation, will cause flaccid paralysis in mice.

Since the recent report by MacCallum and Findlay (8) has stimulated and formed the basis for this part of our work, it might be well to review certain phases of their investigation. During an extended cultivation of a strain of lymphocytic choriomeningitis virus, the virus was carried for 270 consecutive subcultures in Tyrode-serum cultures using chick substrate of varying composition. At the 66th culture generation the injected mice became lethargic and showed spastic and flaccid paralysis. Transfer of the brain of such mice to guinea pigs produced a moderate fever which was followed by cachexia and death. However, retransfer of the blood and brain from such guinea pigs to mice produced once more the typical symptoms of lymphocytic choriomeningitis without spinal involvement. When mice were injected with the 90th subculture, flaccid paralysis occurred again; however, upon transfer to guinea pigs no symptoms were noted, nor were the injected guinea pigs resistant to subsequent inoculation with the W E strain of lymphocytic choriomeningitis virus. On the other hand, when tissue cultures were injected into guinea pigs intracerebrally the characteristic picture of lymphocytic choriomeningitis was seen. While the symptom complex of flaccid paralysis therefore persisted in passages from mouse to mouse conversion of the culture strain to its original state of pathogenicity was evidently accomplished by passage through guinea pigs.

The following experiment was carried out in order to see how murine poliomyelitis virus in tissue culture would react if subjected to experimental conditions similar to those employed by MacCallum and Findlay.

A group of 7 guinea pigs and a group of 15 mice were inoculated with sterile broth, both intraperitoneally and intracerebrally. The doses were 0.75 and 0.5 cc. for the guinea pigs and 0.1 and 0.02 cc. for the mice. No symptoms were noted and no fever occurred in either group of animals. By all accepted standards these particular

groups of animals could be considered free from latent infection with lymphocytic choriomeningitis virus. These animals were segregated and used in the subsequent tests. Three guinea pigs were given 0.1 cc. intracerebrally and 0.75 cc. intraperitoneally of murine tissue culture virus (110th passage). No symptoms were seen and the daily temperature variation was well within normal range for several days. One week after this injection 1 guinea pig was sacrificed. The blood of this guinea pig was injected intraperitoneally (0.15 cc.) and intracerebrally (0.02 cc.) into 3 mice, another group of 3 mice received a similar injection of cord-brain emulsion. Blood or cord-brain suspensions were also transferred to 2 guinea pigs by intraperitoneal or intracerebral injection. The whole procedure was then repeated with blood and cord-brain suspension of 1 of the 2 latter guinea pigs. Again, no symptoms were observed in any of the injected animals.

As a result of this experiment, it becomes clear that when murine poliomyelitis virus is substituted for the virus of lymphocytic choriomeningitis, and the *in vitro* experiments of MacCallum and Findlay are repeated with their original technique, entirely different results are obtained. No lymphocytic choriomeningitis virus was obtained from murine tissue culture.

#### *Interference between Murine Tissue Culture Virus and Poliomyelitis Virus in Monkeys*

In the first study of the murine virus (1) the fact was reported that mouse passage virus, when introduced simultaneously or at short intervals before or after infection with SK or Ayccock monkey poliomyelitis virus, prevented the occurrence of paralysis in the injected monkeys. It now became of interest to ascertain whether the cultured murine virus would act likewise under similar experimental conditions. Three such experiments are herewith recorded.

*Experiment 1*—A total of 10 monkeys was used. Five control monkeys were injected intracerebrally with 0.5 cc. of a 1:100 dilution of SK monkey virus, 3 monkeys received the same dose of SK monkey virus mixed with 0.5 cc. of undiluted murine tissue culture virus, the remaining 2 monkeys received a similar mixture, except that the SK monkey virus was used in a tenfold stronger concentration, *i.e.* 0.5 cc. of a 1:10 dilution. Whereas all 5 control monkeys became paralyzed none of the 3 monkeys which had received a mixture of the same dose of monkey virus (1:100) with murine culture virus developed paralysis. Paralysis did occur, however, in both monkeys which had been injected with the heavier dose of monkey virus (1:10) together with murine culture virus. The outcome of this experiment indicates that murine culture virus will effectively interfere with SK poliomyelitis virus. At the same time there is a suggestion that the interaction between the 2 viruses may proceed on a quantitative basis.

*Experiment 2*—Three control monkeys were injected intracerebrally with 0.5 cc. of a 1:100 dilution of SK monkey virus mixed with 0.5 cc. of uninoculated tissue culture medium. Three additional monkeys were similarly injected, except that

murine tissue culture virus was substituted for the uninoculated medium. In a third group 3 animals received 6 cc. of murine tissue culture virus intravenously immediately following the intracerebral inoculation of 0.5 cc. of 1:100 dilution of SK monkey poliomyelitis virus. Whereas the 3 control animals became paralyzed, all 3 animals receiving the mixture of tissue culture and monkey virus escaped paralysis. Of the monkeys which had received the tissue culture virus intravenously following intracerebral infection with SK poliomyelitis virus 1 animal developed paralysis 1 remained normal, and 1 died after 18 days with questionable symptoms.

*Experiment 3*—Two control monkeys were injected intracerebrally with 0.5 cc. of a 1:100 dilution of Aycock monkey virus. Two additional monkeys received intracerebrally the same dose of monkey virus mixed with 0.5 cc. of undiluted murine tissue culture virus. One last monkey was similarly injected with 0.5 cc. of a 1:10 dilution of Aycock virus mixed with 0.5 cc. of undiluted tissue culture virus. Whereas the two control animals became paralyzed, the two monkeys receiving the mixture of tissue culture virus with the smaller dose of Aycock virus (1:100) remained free from paralysis, on the other hand, the monkey injected with the heavier dose of Aycock virus (1:10) together with murine tissue culture virus became paralyzed.

In summarizing the above results it seems safe to say that effective interference can be obtained in mixture tests between poliomyelitis virus and murine tissue culture virus, provided the experimental animals are not overloaded with too large a dose of monkey virus. If one considers the total number of control and experimental animals involved in the three experiments, it is evident that all 10 control monkeys became paralyzed, whereas 8 animals failed to show any symptoms when murine culture virus was used together with monkey virus in intracerebrally injected mixtures. The limitations of such interference are also apparent from the failure of murine virus to protect against a larger dose of monkey virus. Obviously, the group of animals treated intravenously with murine tissue culture virus is too small to be properly interpreted at this time. But there is at least a suggestion that favorable results may also be secured by peripheral administration of culture virus.

At the time these experiments were run a few tests were also carried out in order to determine whether the murine culture virus *per se* had any demonstrable pathogenicity for monkeys. Accordingly, 4 monkeys were injected intracerebrally with 1.0 cc. of undiluted murine tissue culture virus. None of these animals suffered any ill effects. Temperature readings were within normal range and no abnormal symptoms of any kind were noted. Under the conditions of this test, therefore, the murine culture virus has given no evidence of being pathogenic for *rhesus* monkeys.

#### DISCUSSION

If one reviews the field of virus cultivation one becomes cognizant of the dearth of knowledge concerning the basic processes which take place in a tissue culture when a virus is brought together with living cells. While certain

viruses grow in the presence of chick tissue, apparently with utter disregard for species or type of tissue, other viruses with broad experimental and natural host range possess comparatively rigid cellular requirements. Our study of the behavior of the murine virus on different cellular substrates was approached with a belief that embryonic mouse tissue was the most important single factor necessary for virus growth and that variations in the amount of nervous tissue would produce little change in potency. We felt justified in making this assumption because, in the paralyzed mouse, large amounts of murine virus can be demonstrated not only in the central nervous system, but also in the blood, spleen, liver, adrenals, and lymph nodes. The seemingly systemic distribution of the murine virus was taken to indicate that the parent strain, with its highly developed neurotropism in the monkey, had been transformed into a non-selective agent in the mouse during the adaptive process. It was therefore surprising to find that the level of virus potency showed a distinct tendency to vary in proportion to the amount of nervous tissue in the culture medium, and that, in tissue culture, the murine virus displays more definite affinity for the central nervous system than in the paralyzed mouse. The reasons for this discrepancy may well be due to the fact that the apparent systemic distribution of the murine virus in the mouse is caused by its unusually high virulence.

The results of our studies on the relationship between variations in pH and virus growth appear to justify the emphasis which should be placed upon minute details of the culture system. After many years of cultivating viruses, authorities are still in disagreement as to the condition of the cell which is most receptive for virus propagation. A review of the pertinent opinions, which have been expressed from time to time (9), reveals that some stress the functional activity of cells for proliferation, while others believe the resting state of the cell to be most important. The same confusion exists with regard to the optimum ratio of tissue to fluid medium. The conclusion seems inevitable that when more attention is paid to the physiology of the host cell a better understanding of the virus itself will follow.

As far as the general effect of *in vitro* environment on virus potency is concerned, experience with viruses which have been maintained outside the animal host, either in tissue cultures or in fertilized egg preparations, has shown that three general types of reactions may be expected. First, the virus may undergo no demonstrable change. This class includes equine encephalomyelitis virus (10), influenza virus (11), and the classical example of the virus of fowl plague, which was cultivated for 5 years with fully maintained virulence (12). Or, viruses may become attenuated after continued cultivation, as is true for vaccinia (13). Finally, certain viruses, as the result of prolonged cultivation, undergo profound changes which suggest an alteration in the character of the virus itself (yellow fever virus (14), lymphocytic choriomeningitis virus (8),

and pseudorabies virus (15)) As far as the behavior of murine virus in tissue culture is concerned, some attenuation has evidently taken place in that mice can no longer be infected peripherally with culture virus in doses which prove highly virulent with mouse passage virus. The fact that such mice resist reinfection with passage virus would suggest that the antigenic character of the culture virus had been preserved. Another profound change in pathogenicity is indicated by the fact that cultured murine virus has never infected guinea pigs, although these animals have proven highly susceptible to infection with mouse passage virus at certain phases of its transmission through mice (6). These findings bring to mind similar observations with the yellow fever virus. Interestingly enough, as in the case of yellow fever, cultivation of the poliomyelitis virus succeeded only after the infectious agent had been transmitted from its original host to lower animals. It is of interest, in this connection, to briefly mention the fact that preliminary experiments with the Lansing strain of murine poliomyelitis virus have given evidence of some degree of *in vitro* propagation with the type of tissue culture medium employed in this work. On the other hand, Theiler's virus has failed to grow under similar conditions of cultivation.

In evaluating the data relating to the rate of propagation of the murine virus in tissue culture, the word "propagation" should be used with circumspection. Our present knowledge does not permit us to designate the interaction between virus and cell as a process which leads to an actual numerical increase of infectious particles. To be precise, it is unknown whether multiplication of an infectious virus unit occurs within the culture, or whether the virus particle may not consist of a multiplicity of factors with individually varying antigenic and infectious capacities. The only criterion available at the moment is the measurable increase in virus infectivity for the susceptible host, which stands in direct proportion to the length of time for which the cell has been in contact with the virus. Moreover, the methods of titration in animals are themselves not too satisfactory since they are subject to tremendous variability in host response, and the customary tenfold dilution method, at best, can only be a rough approximation. These facts, although they may be self-evident, bear reassertion when one attempts to interpret data which purport to make available a virus "growth curve." Nevertheless, it has been a source of surprise that repeated experiments have yielded confirmatory results in so far as the measurable increase in virus potency is concerned. Responsible for the regularity of these results is partly the unusual stability of the murine virus and the fact that the pathological symptoms are so clearly dependable. The unusual speed with which infectivity develops in murine virus cultures imitates to a full extent the extraordinary rapidity which characterizes the progress of murine infection in the living animal.

The interference phenomenon and its mechanism will be fully discussed

elsewhere (16) Suffice it to point out here that the observations reported in this paper strongly suggest that cultured murine virus, in principle, is also capable of blocking poliomyelitis virus in monkeys As had previously been suspected, the interaction between the two viruses appears to be quantitative, and the available data are in harmony with this thought Further perfection in the use of culture virus as an interfering agent in poliomyelitic infection must await the development of improved methods which permit a more abundant yield of virus in tissue cultures

#### CONCLUSIONS

1 The murine virus may be grown in embryonic mouse brain-serum ultrafiltrate cultures The virus fails to grow in embryonic chick tissue cultures or in fertilized egg preparations

2 Some relationship can be demonstrated between the amount of nervous tissue and the infectivity of the culture

3 Optimum titers of virus potency ( $10^{-6}$ ) can be obtained by adjusting the pH of the growing culture at 7.3 to 7.6

4 A simple pH inactivation curve for virus alone and for virus when actively growing in tissue culture has been obtained

5 The rate of virus propagation, as determined by potency tests in mice, has been established for cultures which were seeded with large or small amounts of virus The murine virus "grows" relatively fast The optimum titer for a large inoculum was reached in 19 hours, for a small inoculum in 72 hours

6 With extended subcultivation *in vitro* the cultured virus shows a loss of infectivity for mice by peripheral injection However, potency as determined by intracerebral injection remains constant

7 Mice surviving inoculation of culture virus by routes other than intracerebral acquire a relative resistance to reinfection with mouse passage virus

8 The murine culture virus passes without difficulty through collodion membranes with an A.P.D. of 30  $m\mu$  Its particle size may therefore be estimated as lying between 10 to 15  $m\mu$

9 On a basis of *in vitro* activity and cross infection, the murine culture virus is distinct from the virus of lymphocytic choriomeningitis

10 Murine culture virus may be used as an interfering agent to block infection with poliomyelitis virus in monkeys The interaction between the two viruses seems to be quantitatively limited Such interference, with the present potency of culture virus, operates effectively only against comparatively small doses of monkey virus

#### BIBLIOGRAPHY

- 1 Jungeblut, C. W., and Sanders, M., *J. Exp. Med.*, 1940, **72**, 407
- 2 (a) Sanders, M., *J. Exp. Med.*, 1940, **71**, 113 (b) Sanders, M., and Molloy, E., *Proc. Soc. Exp. Biol. and Med.*, 1940, **45**, 327 (c) Molloy, E., *Proc. Soc. Exp. Biol. and Med.*, 1940, **44**, 563

- 3 Simms, H. S., and Sanders, M., *Arch. Path.* in press
- 4 Taylor, A. R., Sharp, D. G., and Beard, J. W., *J. Infect. Dis.* 1940, 67, 59
- 5 Bauer, J. H., and Hughes, T. P., *J. Gen. Physiol.*, 1934, 18, 143
6. (a) Jungeblut, C. W., and Sanders, M., *J. Am. Med. Assn.* 1941, 116, 2136  
(b) Jungeblut, C. W., Feiner, R., and Sanders, M., *J. Exp. Med.*, 1942, 76, in press.
- 7 Casals-Ariet, J., and Webster, L. T., *J. Exp. Med.*, 1940, 71, 147
- 8 MacCallum, F. O., and Findlay, G. M., *Brit. J. Exp. Path.* 1940, 22, 110
- 9 Sanders, M., *Arch. Path.*, 1939, 28, 541
- 10 Beard, J. W., Beard, D., and Finklestein, H., *J. Immunol.*, 1940, 38, 117
- 11 Chambers, L. A., and Henle, W., *Proc. Soc. Exp. Biol. and Med.*, 1941, 48, 481
- 12 Plotz, H., *Compt. rend. Soc. biol.*, 1937, 125, 602
- 13 (a) Goodpasture, E. W., Buddingh, G. J., Richardson, L., and Anderson, K., *Am. J. Hyg.*, 1935, 21, 319 (b) Ellis, R. V., and Boynton, R. E., *Pub. Health Rep., U. S. P. H. S.*, 1939, 54, 1012
- 14 Lloyd, W., Theiler, M., and Ricci, N. L., *Tr. Roy. Soc. Trop. Med. and Hyg.*, 1936, 39, 481
- 15 Glower, R. E., *Brit. J. Exp. Path.*, 1939, 20, 150
- 16 Jungeblut, C. W., and Sanders, M., *J. Exp. Med.* 1942 in press





## MORPHOLOGICAL STRUCTURE OF THE VIRUS OF VACCINIA

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PLATES 20 AND 21

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The morphology of the agents responsible for variola and vaccinia has been the subject of extensive discussion for a number of decades. Of the many forms described by various workers only two are now considered significant, these are the cytoplasmic inclusions of Guarnieri and the minute particles or elementary bodies of Paschen (1). The identification of the elementary body with the infective unit of vaccinia has been established as a result of careful experimentation in several laboratories over a period of years (2-6). Moreover, the idea that the cytoplasmic inclusion represents a colony of elementary bodies has been held by certain workers (7). Elementary bodies of vaccinia are relatively large (236-252  $\mu$  in diameter as estimated from ultracentrifugation data (8)) and this accounts for the frequency with which they have been examined in the stained state by ordinary microscopy, as well as by means of ultraviolet light in unstained preparations (9), and more recently by the aid of the electron microscope (10). In spite of this work evidence of internal structure in the elementary body has not previously been recorded. The purpose of this report is to present a series of electron micrographs which show that the virus particles of vaccinia possess definite morphological structure.

### *Materials and Methods*

*Virus*—Suspensions of washed elementary bodies of vaccinia were prepared by a method (11) based on the technique of Craigie (4). For certain of the lots of virus, however, the machine recently described by Pickels (12) was used instead of the Swedish angle centrifuge. Satisfactory sedimentation has been obtained with this new apparatus by spinning the virus suspension at 12,400 R.P.M. for 20 minutes in lusteroid tubes having an internal diameter of 11 mm. Sedimented virus was re-suspended with the aid of a rubber plunger which had been shaped to conform closely to the side and bottom of the tube. This modification of the original technique of Craigie (4, 11) saves time, and the final virus preparations are of the same degree of purity (6) since their infective unit-elementary body ratios compare favorably with those of lots prepared in the angle centrifuge.

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*Preparation of Specimens for Electron Microscopy*—The general technique of electron microscopy has been recently described (13), hence, only the details of the procedure which are of importance in the study of vaccinia need be mentioned. One drop of a stock suspension of washed virus was placed on a thin collodion membrane which was attached to a fine mesh wire screen for support. A few seconds later the drop was removed as completely as possible with a fine capillary pipette. In this way relatively few virus particles were brought into contact with the membrane, those which became attached were rarely lost during subsequent manipulation because of the adhesive nature of the surface of the elementary body. The surface of the membrane was then thoroughly washed by submersing it repeatedly in a solution of physiological saline and subsequently in distilled water. After excess fluid had been removed by means of a capillary pipette, the preparation was rapidly dried in the air and placed in the RCA electron microscope (13). Preliminary observations indicated that the effect of various agents on the structure of the virus could best be studied by applying the test materials directly to films of active elementary bodies which had been prepared as described. Following treatment the films were again washed in saline solution and in water.

#### EXPERIMENTAL

Elementary bodies of vaccinia when viewed by electron microscopy present a high degree of regularity of external outline and of internal form. The particles are almost rectangular in shape and usually possess five circumscribed areas which are more dense than the surrounding substance and hence appear darker in the electron micrograph, as shown in Fig 1*a*. The central area of condensation in the elementary body is slightly larger than the others which are spread around it, their general arrangement suggests that of the five spots on dice (Fig 1*b*). Elementary bodies which are joined by a narrow bridge of material of lighter density than the bodies themselves are not infrequently encountered (Fig 1*a*). In one instance a break in the collodion film with a subsequent folding back of the newly formed edge occurred during exposure to the electron beam. This permitted a side view of the particles which in the new position appeared to have flat tops and bottoms (Fig 4) similar to the side walls when viewed from above (Fig 1*a*). Thus, the general shape of the virus particles seems to resemble a brick. Electron micrographs of preparations of elementary bodies which had been rendered non-infectious by heating at 56°C for 1 hour were indistinguishable from those of active virus particles. Similarly, films of elementary bodies prepared in the usual way and then completely dehydrated in a vacuum jar over phosphorus pentoxide showed virus particles with the regular internal structure. Finally, specimens with elementary bodies which had been frozen while on the collodion membrane and then dried from the frozen state contained virus particles with areas of condensation similar to those shown in Fig 1*a*.

Alkaline treatment of elementary bodies liberates a nucleoprotein antigen

(14) from the particles without completely dissolving them. The structures which remain after extraction stain less deeply with silver, are less brilliant in dark field illumination, and sediment less readily in the centrifuge than do active elementary bodies (14). Therefore, it seemed desirable to observe by electron microscopy the various stages of dissolution of elementary bodies caused by alkali. Partially and completely extracted virus particles are illustrated in Figs. 2 and 3. The virus is noticeably affected by treatment with  $N/50$  NaOH for  $\frac{1}{2}$  minute at room temperature (Fig. 2). Certain of the bodies are swollen with rounded outlines and fuzzy edges, their substance is less dense than normal and their areas of condensation stand out prominently. Extraction with  $N/10$  NaOH for 10 minutes takes the virus particles almost completely, and even the condensed areas have practically disappeared (Fig. 3). Certain of the ghosts formed in this manner have ruptured, some have wedge-shaped gaps in their surfaces and others show substance streaming from them.

The morphological evidence obtained by electron microscopy does not permit one to designate the limiting structure which separates the virus from the surrounding medium as a semipermeable membrane. All that can be said is that the surfaces of the bodies under examination appear to be different from the main internal constituents. This is borne out by the occurrence of bridges of material joining aggregated elementary bodies (Fig. 1a) and by the streaming out of internal substance from one point on the surface (Fig. 3). The nature of the limiting membrane remains to be determined.

The high degree of purity of the final preparations of virus is clearly demonstrated in the electron micrographs. The paucity of extraneous material in those portions of the field between elementary bodies in Fig. 1a is immediately apparent. Crude suspensions of dermal pulp which are rich in elementary bodies contain much non-viral material. Films prepared from supernatant fluid obtained from such suspensions after the virus had been sedimented contain unnumberable tiny particles of different sizes and shapes (Fig. 5). The supernatant fluid was applied to the film and subsequently washed in a manner identical with that used for suspensions of virus, yet no structures which simulate elementary bodies are seen (Fig. 5). While part of the amorphous material shown in this figure might consist of the soluble LS-antigen of vaccinia, most of it probably represents small bits of cellular debris, in any case, it is discarded in the process of purifying the virus. The granular material present in the background of Figs. 2 and 3 is probably nucleoprotein which was extracted from the elementary bodies by alkali and which was not completely removed from the film by subsequent washing. It will be recalled that this nucleoprotein is relatively insoluble in aqueous solutions having a pH near 7.0 (14).

Soluble proteins are easily washed from the collodion films by rinsing in

saline solution and then distilled water. Fig 6 illustrates the findings in a film of elementary bodies prepared in the usual way and then treated with a drop of antivaccinal rabbit serum and subsequently washed. Little if any of the antiserum remains on the membrane for the background is essentially clean. Some of the antibody has apparently remained attached to the virus particles, however, for they are more dense than usual since the electron beam failed to penetrate sufficiently to bring out internal structures such as are seen in Fig 1a. Normal rabbit serum employed in similar experiments is removed from the virus by the subsequent washing, as evidenced by the elementary bodies so treated having sharp outlines and recognizable areas of condensation. It must be emphasized that inadequate washing of virus particles immediately prior to examination in the electron microscope will give results like those illustrated in Fig 6. This is true even when untreated stock suspensions of purified virus are employed. Inasmuch as a few ghosts are encountered in all suspensions studied, there apparently is sufficient constant destruction of elementary bodies to provide protein which is adsorbed on the surface of the remaining elementary bodies, thus rendering them more opaque than those illustrated in Fig 1a.

The results of an additional control experiment are illustrated in Fig 7. A suspension of triturated normal rabbit kidney tissue was subjected to the same procedure of differential centrifugation employed for vaccine virus and films were prepared in the usual way from the final suspension of particles. None of the material represented in Fig 7 resembles elementary bodies closely and most of it is strikingly different from the virus. The large spherical masses are interesting but their nature is not apparent, they may represent certain of the particles observed by ordinary microscopy in preparations from normal cells (15).

#### DISCUSSION

Former observations made in the course of our studies of the virus of vaccinia have led us to believe that this agent might be regarded as a complex entity which perhaps resembles certain bacteria more closely than it does the crystalline plant viruses. Indeed, the virus of vaccinia may differ principally from members of the bacterial species in its size and fastidious growth requirements, only living cells from certain animal species are capable of serving as adequate culture media for the virus and this may be because the elementary bodies lack some enzyme systems essential for independent growth and metabolism. The basis for the idea that the virus of vaccinia resembles certain bacteria has been provided by several types of experimental data. For example, elementary bodies apparently respond to osmotic influences (16), they have certain chemical and biologically active constituents in common with living cells (11, 17), and they are antigenically complex (14, 18). The observations recorded in this paper indicate that vaccine virus has a

morphological structure which in many respects approaches that of bacteria (10, 19) and differs from that of the plant viruses (20)

### SUMMARY

The pictorial data obtained by means of the electron microscope indicate a remarkable regularity in the morphology of the elementary body of vaccinia. The virus particles apparently have internal structure and some sort of limiting membrane.

### BIBLIOGRAPHY

- 1 Blaxall, F R., Smallpox, in A system of bacteriology in relation to medicine London, His Majesty's Stationery Office, 1930, 7, 99
- 2 Eagles, G H., and Ledingham, J C G, *Lancet*, 1932, 1, 823
- 3 Nauck, E G, and Paschen, E., *Centr Bakt*, 1 Abt, Orig, 1932, 124, 91
- 4 Craigie, J, *Brit J Exp Path*, 1932, 13, 259
- 5 (a) Parker, R. F *J Exp Med*, 1938, 67, 725 (b) Parker, R. F, Bronson, L H., and Green, R. H., *J Exp Med*, 1941, 74, 263
- 6 Smadel, J E., Rivers, T M., and Pickels, E G, *J Exp Med*, 1939, 70, 379
- 7 Bland, J O W, and Robinow C F, *J Path and Bact*, 1939, 48, 381
- 8 Pickels, E G, and Smadel J E, *J Exp Med* 1938, 68, 583
- 9 Barnard, J E, *Brit J Exp Path*, 1935, 16, 129
- 10 von Bornes, B Ruska E., and Ruska, H., *Klin Woch*, 1938, 17, 921
- 11 Hoagland, C L., Smadel, J E, and Rivers, T M., *J Exp Med*, 1940 71, 737
- 12 Pickels, E G, *Rev Scient Instr*, 1942 13, 101
- 13 (a) Marton, L, *J Bact*, 1941, 41, 397 (b) Zworykin, V K., Hillier, J, and Vance, A. W, *Elec Eng*, 1941, 60, Trans. 157 (c) Anderson, T F, The study of colloids in the electron microscope, in Kraemer, E. O, *Advances in colloid science*, New York Interscience Publishers, Inc., 1942
- 14 (a) Smadel, J E, Lavin, G I and Dubos, R. J, *J Exp Med*, 1940, 71, 373 (b) Smadel, J E, Rivers, T M and Hoagland, C L, *Arch Path*, 1942, in press.
- 15 (a) Claude, A., *Tr New York Acad Sc* 1942 4, 79 (b) Rous P, and Robert son, O H *J Exp Med*, 1917 25, 651
- 16 Smadel J E, Pickels, E. G, and Shedlovsky T *J Exp Med* 1938 68, 607
- 17 (a) Hoagland, C L., Lavin, G I Smadel, J E, and Rivers, T M, *J Exp Med.*, 1940 72, 139 (b) Hoagland, C L., Ward S M Smadel, J E and Rivers, T M, *Proc Soc Exp Biol and Med* 1940 45, 669 (c) Hoagland C L, Ward, S M, Smadel J E., and Rivers, T M *J Exp Med* 1941, 74, 69 (d) Hoagland C L, Ward, S M. Smadel, J E and Rivers T M, *J Exp Med* 1941 74, 133
18. (a) Smadel, J E and Rivers, T M, *J Exp Med*, 1942, 75, 151 (b) Shedlovsky, T, and Smadel, J E, *J Exp Med*, 1942 75, 165
- 19 (a) Mudd S, and Lackman, D B, *J Bact* 1941, 41, 415 (b) Morton H. E and Anderson T F, *Proc. Soc Exp Biol and Med* 1941, 46, 272
- 20 (a) Kausche, G A, Pfankuch E., and Ruska, H. *Naturwissenschaften* 1939, 27, 292 (b) Anderson, T F, and Stanley, W M, *J Biol Chem*, 1941, 139, 339

## EXPLANATION OF PLATES

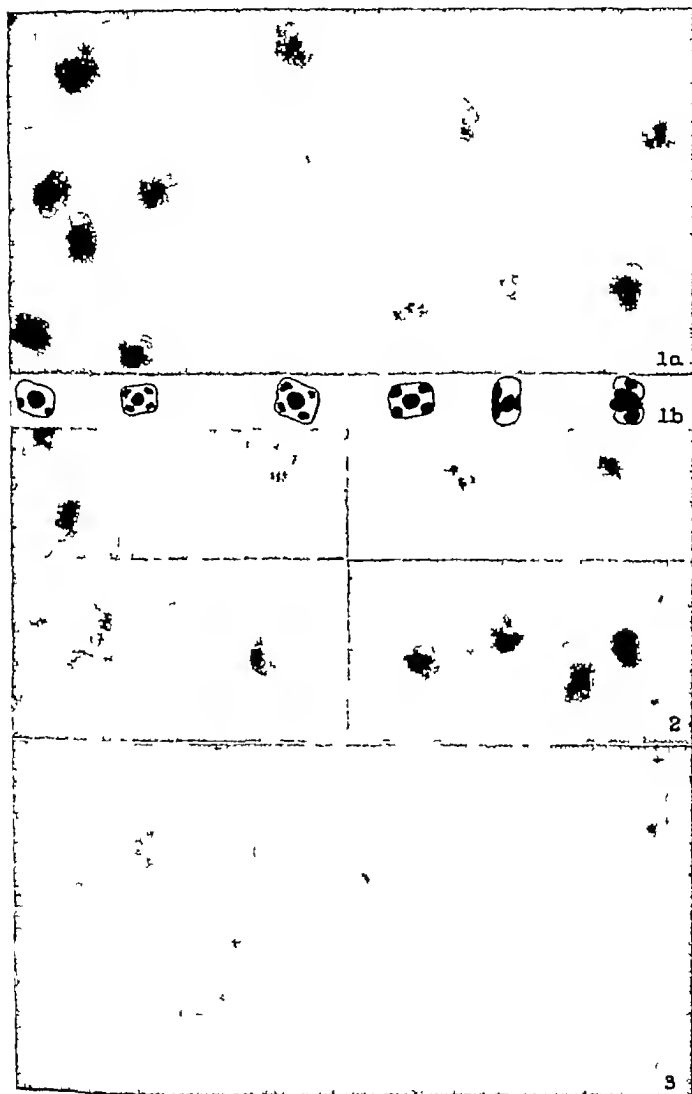
## PLATE 20

FIG 1 *a* Reproduction of an electron micrograph of a purified preparation of elementary bodies of vaccinia. Rectangular shaped virus particles containing dark circumscribed areas are seen. Little extraneous material is present. Magnification  $7100 \times 4$ .

FIG 1 *b* A schematic representation of certain of the virus particles shown in Fig 1 *a*, each drawing is placed beneath the body it typifies.

FIG 2 Combined portions of several electron micrographs illustrate the effects of  $N/50$  NaOH on Paschen bodies. Some virus particles appear almost normal, *i.e.*, they are rectangular with sharp outlines and internal areas of condensation. Others are swollen and rounded with fuzzy outlines, the substance of these bodies is pale and the darker areas of condensation stand out prominently. The granular debris probably represents nucleoprotein extracted from the virus particles. Magnification  $7100 \times 4$ .

FIG 3 Elementary bodies extracted with  $N/10$  NaOH. The virus particles have been laked by the alkali, they are swollen and pale and the areas of condensation have almost disappeared. Certain bodies show wedge-shaped breaks in their surfaces. A stream of internal substance appears to have flowed from the elementary body at the bottom of the figure. Magnification  $7100 \times 4$ .



## PLATE 21

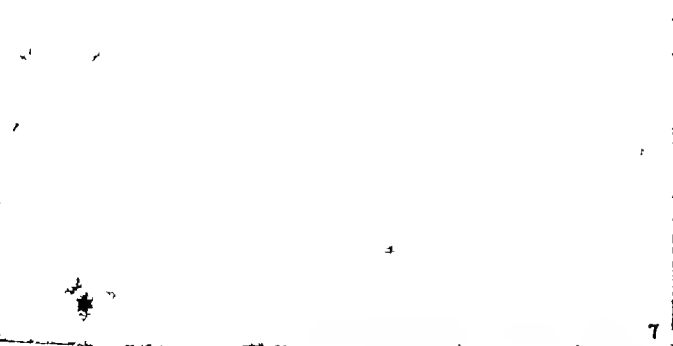
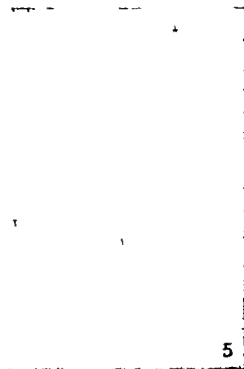
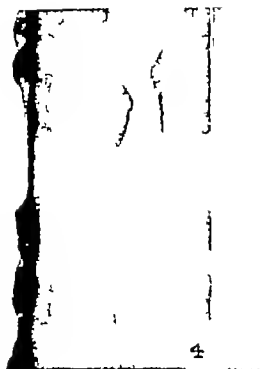
FIG 4 The collodion membrane has broken and folded back, revealing some of the virus particles in profile. The bodies seen at the left of the figure appear to have essentially flat tops and bottoms. Hence, the shape of the elementary bodies seems to resemble a brick. Magnification  $7100 \times 4$

FIG 5 A suspension of crude vaccine dermal pulp from which the virus particles have been removed by centrifugation. No structures which resemble elementary bodies are seen. Magnification  $7100 \times 4$

FIG 6 A film of elementary bodies such as those illustrated in Fig 1 *a* was prepared and then treated with a drop of antivaccinal serum. This was washed off with saline solution and water. Evidence of internal structure in the virus particles is not convincing and the outlines of the bodies are not sharp. A similar effect is produced by the non-specific adsorption of other types of protein on the surface of the elementary bodies (see text). Magnification  $7100 \times 4$

FIG 7 Normal kidney cell particles were obtained from a suspension of rabbit kidney tissue by the same procedure of differential centrifugation employed for vaccine virus. Bizarre structures are present in the illustration but none simulate the elementary bodies seen in Fig 1 *a*. Magnification  $7100 \times 4$







# THE HISTOGENESIS OF CELLS IN EXPERIMENTAL PNEUMONIA IN THE DOG\*

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PLATES 22 TO 26

(Received for publication, March 13, 1942)

The present study concerns itself principally with the origin of the cells and the sequence with which they appear in the exudate in experimentally produced pneumonia in the dog, which simulates closely both clinically and pathologically the disease occurring spontaneously in man. The general characteristics of the pathology and pathogenesis of experimental canine pneumonia have been described by Robertson and associates (1, 2) in previous reports from this laboratory. These earlier studies left open many questions, and with the development of new techniques, a further investigation of certain aspects of the evolution of the pneumonic lesion seemed to be indicated.

In addition to the study of the histogenesis of the cells of the inflammatory exudate, concomitant observations were made on the distribution of pneumococci, and other changes occurring during the different stages of the developing lesion. The present findings will be given in some detail not only for the sake of giving as complete a review as possible, but also because they have resulted in a reinterpretation of certain of the original observations. This will be brought out during the course of the discussion.

In order to study the evolution of the inflammatory process from its earliest inception to its termination, a series of animals were sacrificed at varying intervals of time after inoculation. The intervals were short in the early stages when the lesions were enlarging and were gradually lengthened as the disease progressed to its termination with recovery. Only specimens of lungs fixed immediately after death from sacrificed animals were used. Intrabronchial fixation and special staining techniques were employed to give the maximum cytological and histological detail. Several sections were taken from the consolidated lobes of each animal so that the cytological differences, if any, in various parts of the lesions could be studied in relation to the primary site of infection. When studying the cellular changes in the exudate and lung tissues, the more recent concepts of lung structure as well as the fundamental concept of cellular reactions in inflammation, in general, were kept in mind.

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### *Material and Methods*

*Dogs, Dosage, and Method of Inoculation*—Forty-seven apparently healthy dogs varying in weight from 8 to 14 kilos were used. The method employed in infecting the animals was devised by Terrell, Robertson, and Coggeshall (3). Briefly, it is as follows. After the dog was placed under morphine anesthesia and its larynx cocaine-ized, pneumococci suspended in a 5 per cent starch-broth mixture were injected through a radio-opaque catheter (No. 9) introduced through the trachea into one of the lower lobe bronchi with the aid of a fluoroscope. The dosage varied from 0.01 to 0.05 cc. of an 18 hour broth culture of strain A<sub>5</sub> Type I pneumococcus suspended in 1 cc. of the starch-broth medium. With this method and dosage lobar pneumonia is produced in approximately 100 per cent of inoculations from which 90 per cent of the dogs recover (4). The clinical course of the disease was followed by daily observations in temperature, pulse, white blood cell count, and one or more roentgenograms until the animals were sacrificed or had recovered from the disease.

*Single Infections*—Thirty-seven dogs were sacrificed at increasing intervals of time from 1 hour to 22 days after inoculation. Fourteen were killed at from 1 to 3 hour intervals within the first 24 hours, 10 at 6 hour intervals from 24 to 72 hours, and 13 from 4 to 22 days after the onset of their infections. All the dogs except one, which was killed during the first 48 hours, showed clinical evidence of active infections. Most of the dogs killed at later intervals had recovered on the 3rd or 4th day of the disease.

*Reinfected Dogs*—Ten dogs were subjected to reinoculation in the same lobes from 3 to 4 weeks after the onset of their first infection. At the time of their second inoculation they had completely recovered from their previous disease and their lungs were clear by x-ray. They were sacrificed at 2, 4, 8, 12, 18, 22, 32, 41, 50, and 72 hours after inoculation. All the dogs except the 2 killed at 50 and 72 hours showed clinical evidence of active infection.

*Method of Fixing Lungs*—The method of fixing the pneumonic lungs was the same as that used by the author (5) during his study of the pores of Kohn (6) in mammalian lungs, including those of the dog. Briefly, it was as follows. The animal was given intravenously a lethal dose (75 mg. per kilo of body weight) of pentobarbital sodium, which produced immediate death. The heart and lungs were quickly exposed, the aorta clamped, and the heart gently squeezed, after which a ligature was tied about the base of the heart to hold the blood in the congested pulmonary vascular system when the lungs were reexpanded with the fixing solution. Zenker-formol solution (9 parts of Zenker's fluid, without acetic acid, to one part neutral formalin) was used and introduced into the lungs through the trachea under low gravity pressure until the uninvolved lobes were reexpanded approximately to their normal inflated size. At the same time the fixing fluid also penetrated throughout the consolidated lobes. After ligating the trachea, the heart and lungs were removed *in toto* and immersed in the fixing solution for from 6 to 10 hours. The procedure from the time an animal was killed until its lungs were injected with the fixative took from 3 to 5 minutes.

*Specimens for Microscopic Study*—After fixation several specimens were taken from the consolidated lobes of each animal. They were numbered and a record of the area from where they were taken was noted on diagrams of the lungs drawn in the

protocols. Control sections from uninvolved lobes were taken from each animal. Specimens from some animals were embedded in paraffin and those from others in nitrocellulose. All specimens were sectioned from 8 to 10 microns in thickness and placed serially on slides. Some of the sectioned tissues from each animal were stained with Maximow's (7) hematoxylin-eosin-azure II stain for cytological and histological details, others with Heidenhain's (7) azan stain for connective tissue, and others with Wallace's (8) modified Gram Weigert stain for pneumococci fibrin, and general histological detail.

*Observations*—The observations on the clinical course of the disease in these series of dogs were similar to those noted by Terrell, Robertson, and Coggeshall (3), and Coggeshall and Robertson (9), during previous studies in the same animal and, therefore, will not be included in this report. The protocols of the individual animals will not be included because of lack of space. Spread of the infection occurred in 11 of the singly infected animals, but only the findings in the inoculated lobes will be presented. The data concerning the histogenesis of cells in the lungs of the reinjected animals will be given only in summary.

#### *Pathogenesis of Lobar Consolidation*

*Macroscopic Observations*—The inflammatory process began in a small area at the site of inoculation subjacent to the pleura in the peripheral anterolateral region of the lobe. It enlarged in a contiguous and progressive manner so that approximately the whole lobe became consolidated within the first 24 hours after inoculation. The consolidated portions, regardless of size, of the lobes of the 14 animals killed within this time, were indurated, irregular in outline, and sharply demarcated from the uninvolved portions. The spreading margins of the lesions showed advancing borders of edematous and congested tissue, in which were small, red, inflammatory foci similar to the patchy beginning lesions at the sites of inoculation in the lungs of the animals killed between 1 and 4 hours. These foci blended to form the enlarging, uniformly consolidated areas. The anterior dependent portions of the lobes first became consolidated, then the inflammation spread posteriorly until the level of the hilum was reached. The last portion of the inoculated lobe to become consolidated, which occurred at about 36 hours, was the region about its superior posterior angle, which lies posterior to the main stem bronchus near the hilum. A fibrinous exudate was usually present on the pleural surfaces of the consolidated portions of the lungs of the animals killed between 6 and 48 hours after inoculation.

It was impossible in the gross to divide the individual lesions, either in the fresh or fixed state, into stages of congestion, red and gray hepatization, and resolution. The fixed, partially consolidated lobes, seen from their cut surfaces of the animals killed during the first 24 hours after inoculation varied in color from grayish, at their centers, to brownish red, at their margins. As the consolidated areas enlarged, the grayish-red areas became correspondingly larger while the brownish red areas were confined to a relatively narrow margin at their borders. The completely consolidated lobes of the animals killed from 36 to 96 hours after inoculation had approximately the same grayish red appearance. Those from animals killed after this time gradually returned to their normal reddish color as resolution, which was usually complete from 8 to 10 days after inoculation, took place.

*Microscopic Observations*—At 1 hour after inoculation, leucocytes had already begun to congest the capillaries and enter the air spaces at points along the septal walls at the site of inoculation. Only a few pneumococci could be seen suspended in the starch inoculum. After this time the inflammatory process increased in intensity and extent so that by 4 hours it had spread well beyond the site of inoculation. The focal areas had coalesced and the cellular exudate rather uniformly filled the air spaces, although the consolidated area occupied only a small portion of the lobe. Toward the margin of the lesions there were fewer cells in the exudate which consisted principally of serous fluid containing large numbers of pneumococci. Beyond the zone of edema-filled alveoli where the lung spaces contained apparently no fluid and the septal walls appeared normal under low power magnification, many pneumococci could be seen, under high magnification, lying in a thin layer of edema fluid on the alveolar surfaces and in the pores of Kohn.

The spreading borders of the enlarging areas of consolidation in the animals killed at later intervals during the first 36 hours of the disease had essentially the same microscopic appearance as did those of the 4 hour lesion. Serous exudate partially or completely filling the air spaces and containing large numbers of pneumococci was the characteristic feature (Figs 1 to 3). The extent of the zone of edema and the number of organisms, however, varied in individual lesions. As the inflammatory process spread within the lobe, pneumococci diminished in numbers as cells increased in the exudate in the older areas of involvement. Thus in the consolidated lobe of the animal killed at 36 hours, many pneumococci were present in the air spaces of the recently involved portions of the lobes (Figs 1 to 4) while none were seen in the exudate at or near the site of inoculation (Fig 11). Phagocytosis of the pneumococci within the air spaces by the exudate cells, although it varied in individual lesions, appeared to be the chief means by which the exudate was cleared of organisms (Figs 3 to 5). Phagocytosis of the intraalveolar organisms occurred in animals having severe septicemias. This is seen in the pneumonic exudate (Figs 3 to 5, 11, and 12) of the animal which when killed at 36 hours had a bacteremia of a thousand colonies of Type I pneumococcus per cc of blood. Pneumococci gradually disappeared from the exudate in the lungs of the animals killed after 36 hours. Pneumococci were seldom seen in the exudate in any part of the consolidated inoculated lobes of animals killed after 72 hours, although some animals were bacteremic and had suffered spread of their infections to other lobes by this time.

Pneumococci were never seen in the substance of the alveolar walls beyond the margins of, at, or within the developing lesions (Figs 1 to 5, 11, and 12). At points where the leucocytes were leaving the capillaries, they were not seen in the substance of the septa (Figs 6 and 7). The interstitial tissue of the pleura, blood vessels, and bronchi showed varying degrees of involvement which was never marked in the early lesions. In some areas the interstitial tissue was edematous, contained fibrin deposits, and was infiltrated with polymorphonuclear leucocytes, while other areas showed no reaction, yet the air spaces and bronchi in both regions showed the same degree of consolidation. In the early lesion organisms were seldom seen in the interstitial tissue showing an inflammatory reaction, and they were never seen in the congested lymphatics even though the adjoining air spaces contained large numbers. Large numbers of organisms, lying on the surfaces of epithelial lining cells, were pres-

ent in the bronchial exudate in the early lesions, but none were seen within or between these cells or invading the underlying connective tissue. Pneumococci were never seen in the lumina of the capillaries or blood vessels, although some of the animals were bacteremic at the time of death.

In spite of the intense inflammatory reaction which took place in the inoculated lobes, it resulted in little alteration of the general architecture of the lung parenchyma. No capillary or vascular thromboses were seen in any of the lesions. The small areas of lung which were traumatized by the starch inoculum healed by formation of a fibrotic scar. The remaining parts of the consolidated lobes underwent resolution. This began in focal areas usually near the sites of inoculation where the pneumonic process began. Beginning resolution was present in the lungs of the animals sacrificed at 72 hours and increased in extent although in an irregular manner, in the inoculated lobes of those sacrificed after this time. It proceeded more rapidly in some animals than in others (Figs. 15 and 16), but was more or less complete in those sacrificed at 10 days or longer after the onset of the disease. Small focal areas of organization of the exudate which had collected in the alveolar ducts and respiratory bronchioles were noted in some of the recovered lungs (Figs. 17 and 18).

### *Histogenesis of Cells in the Exudate*

During the course of the disease in these series of animals, quantitative and qualitative changes gradually took place in the cellular constituents of the pneumonic exudate. The exudate changed from one consisting principally of polymorphonuclear leucocytes to one of large mononuclear macrophages. The various kinds of cells will be discussed in the order of their appearance in the air spaces.

*Pigment Filled Mononuclear Macrophages*—Large, free, mononuclear cells containing dust pigment were present in small numbers in the air spaces of normal lungs of dogs. Such cells were also seen in the control sections from uninvolved lobes in this series of animals and also in the exudate in all the early lesions (Fig. 7). They ingested pneumococci, red blood cells, and polymorphonuclear leucocytes. In the older lesions these could not be distinguished from the many pigment filled mononuclear macrophages which developed in response to the acute pneumococcal infection (Figs. 15 and 16).

*Polymorphonuclear Leucocytes*—The polymorphonuclear leucocytes were the first cells to appear in large numbers in the air spaces in response to the implanted pneumococci. They entered the exudate principally from the alveolar capillaries and small blood vessels. In the 1 hour lesions some were already in the spaces while large numbers filled the capillaries and small blood vessels. They left the capillaries in groups forming asteroid configurations at many points along the septa (Figs. 6 and 7). The exudation of leucocytes soon followed the appearance of the infected edema fluid in the air spaces and thus was most pronounced in areas bordering the zone of edema. To a lesser extent, however, leucocytes could be seen entering the air spaces in sections taken from all parts of the consolidated areas during the first 24 hours of the disease when consolidation was taking place. Some of these cells passed directly

through the walls of the larger pulmonary, bronchial, and pleural vessels into the interstitial tissue, while others leaving the bronchial vessels passed directly into the bronchial exudate between the intact bronchial epithelial lining cells. The character of the exudate in the bronchi was similar to that in the finer air spaces. Regardless of their phagocytic activity, the polymorphonuclear leucocytes soon began to degenerate after entering the air spaces. Although they were the most numerous cell type in the exudate up to 48 hours, many at this time had pycnotic nuclei and had been taken up by the mononuclear macrophages (Fig 13). In the 72 hour lesion the majority were undergoing degeneration. In the 4 day lesion where resolution had begun only a few non-degenerative forms were seen. In still older resolving lesions these gradually disappeared from the air spaces (Figs 15 and 16).

*Lymphocytes and Monocytes*—The lymphocytes and monocytes of the blood entered the exudate in the early stages of the disease along with the polymorphonuclear leucocytes. At first they were inconspicuous because of the predominance of the latter cells. In consecutively older lesions the hematogenous mononuclear exudate cells increased in numbers in the exudate and at the same time underwent morphological changes. These consisted of hypertrophy and transformation into large mononuclear cells which gradually assumed the appearance and phagocytic properties of typical macrophages. In the lesions of the animals killed within the first 8 hours after inoculation (Fig 8), the majority of the small hematogenous mononuclear exudate cells were identical in appearance with the lymphocytes still within the lumina of the capillaries and blood vessels. A few resembled the monocytes of the blood. Once in the exudate they began to enlarge. Their nuclei (both lymphocytes and monocytes) became less compact, more vesicular, and assumed many shapes, and their cytoplasm increased in amount and became less basophilic. As the lymphocytes and monocytes first entering the exudate hypertrophied other small varieties continued to enter the air spaces, so that lesions of the animals killed between 8 and 36 hours after infection showed hematogenous mononuclear exudate cells of many sizes and shapes (Figs 8 to 13). Many of these polyblastic exudate cells in the 12 to 24 hour lesions resembled monocytes of the blood, although the proportion of the latter cells to lymphocytes still within the blood had not increased.<sup>1</sup> Cells representing all transitional stages in the development of lymphocytes into monocytes and monocytes into small macrophages could be seen in the exudate. It was impossible to separate them into groups representing typical lymphocytes, monocytes, or macrophages (Figs 9 to 12).

In the lesions of the animals killed from 15 to 36 hours after inoculation the number of large mononuclear cells showing phagocytic properties increased while the number of the smaller non-phagocytic varieties decreased (Figs 9 to 11). By 36 hours the majority of the hematogenous mononuclear exudate cells had transformed themselves into macrophages, which had ingested red blood cells, pneumococci, and degenerating polymorphonuclear leucocytes (Fig 11). In sections of the 36 hour lesion from areas which were more recently consolidated (Fig 12), many of the mononuclear cells were of the smaller non-phagocytic variety, resembling the polyblastic mononuclear cells

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<sup>1</sup> The cellular changes which took place in the peripheral blood and blood-forming organs will be given in a subsequent report.



in the exudate of the earlier lesions (Figs. 8 and 9). In the lesions of the animals killed from 48 to 72 hours after inoculation, the mononuclear macrophages became still larger and more numerous, but a few small non phagocytic cells resembling lymphocytes and monocytes were present in the exudate until resolution was well advanced (Figs. 13 and 14). Degenerative forms of lymphocytes and monocytes were not seen in any of the lesions at any stage of the disease.

*Septal Cells (Alveolar Epithelial Cells)*—The term 'septal cell' (10) refers to the cuboidal cells on the alveolar walls which in the past have been called alveolar epithelium. In the early developing pneumonic consolidations, the septal cells were slow to react to the intraalveolar infection and did not become detached (desquamated) from the alveolar surfaces when the exudation of serous fluid and leucocytes from the blood took place (Fig. 7). The first change noted in these cells was an increase in their size which became apparent in the 15 hour lesion (Fig. 9). In the 18, 21, 24, 30 and 36 hour lesions, the septal cells became progressively more prominent and appeared to be more numerous on the walls (Figs. 11 and 12). They hypertrophied in a uniform manner so that in any given lesion the septal cells were approximately the same size. They were large and conspicuous in older lesions until resolution was advanced (Figs. 15 and 16). As the septal cell increased in size, its nucleus remained oval and vesicular while its cytoplasm increased in quantity, lost its vacuoles and became more basophilic. In lesions which were resolving, vacuoles again accumulated in their cytoplasm. The septal cells did not increase sufficiently in number during any stage of the disease to form a continuous covering over the alveolar surfaces, but appeared as isolated cells (Figs. 14 to 16). They were intimately associated with the connective tissue elements in the septa, for frequently their cytoplasm could be seen to extend into the interalveolar connective tissue stroma or across the septa to project into the adjoined alveolar spaces (Fig. 16).

It was difficult to determine how many of the septal cells became detached to contribute to the source of the alveolar macrophages, for many of the latter cells derived from the hypertrophy of the hematogenous lymphocytes and monocytes were present in the exudate before these local cells became conspicuous on the walls. Mitotic or amitotic figures, indicating proliferation, were rarely seen in the enlarged septal cells, and then only in 2½ day, 3 day and some of the older lesions undergoing resolution. In the lesions showing occasional mitotic figures in septal cells binucleated septal cells also were seen on the alveolar walls. Such binucleated cells were rarely seen in the exudate. Smaller developing septal cells were not seen in the alveolar walls to take the place of the larger ones should they desquamate without dividing and there was rarely seen constriction of the cytoplasm at the attached portions of the large septal cells to suggest that they were going to free themselves and enter the exudate. The septal cells remained large and conspicuous on the walls throughout resolution although the macrophages in the exudate diminished in number (Fig. 16).

Although the hypertrophied septal cells did resemble the large, free phagocytic mononuclear cells in the exudate (Fig. 15) the former showed no phagocytic activity in any stage of the disease. In the early developing lesions pneumococci were frequently seen lying on the free surfaces of septal cells with none in their cytoplasm. In the later stages of the disease when the polymorphonuclear leucocytes and red blood cells were degenerating none were seen in the septal cells while large numbers were ingested by the free mononuclear cells in the exudate (Figs. 10, 11 and 13).

*Fixed Histocytes (Tissue Macrophages)*

Mononuclear cells, other than the septal cells described above, were not observed to develop in or on the septal walls and enter the exudate in any stage of the disease. New histiocytes or the old pigment-filled ones in the interstitial tissue of the bronchial, blood-vessel, and pleural walls, were not seen to mobilize and enter the exudate. Mononuclear cells containing pigment in their cytoplasm increased in the interstitial tissue in the lesions undergoing resolution when the number of macrophages were decreasing in the exudate. These were similar morphologically to those in the alveolar spaces. Numerous smaller deeply basophilic mononuclear cells also accumulated in the interstitial tissue in the resolving lesions. The majority of these cells were of the lymphocyte and plasma cell varieties. Mitotic figures in these cells were not infrequently seen in the recovering lesions. Plasma cells were occasionally seen in the resolving lung exudate (Fig. 15).

*Fibroblasts*—Fibroblasts in the interstitial tissue of the alveolar, pleural, vessel, or bronchial walls were not observed to give rise to cells which entered the exudate and functioned as macrophages.

*Endothelial Cells*—There was no evidence that the cells lining the blood vessels, capillaries, and lymphatics of the lungs contributed either to the small or large mononuclear cells in the exudate in any stage of the disease. They remained flattened and intact when the blood leucocytes entering the air spaces passed through the vessel or capillary walls. The endothelial cells showed no phagocytic activity and were apparently not injured by the mechanical distortion produced by the migrating leucocytes, for thrombosis of the capillaries or larger vessels was not seen in the lesions of any of the animals.

*Megakaryocytes*—Megakaryocytes, which were occasionally seen in the septal capillaries of the normal lungs, were also present in the capillaries in all the lesions. They appeared to be no more numerous in the pneumonic lungs. As far as could be determined, these cells did not enter the exudate during the course of the disease.

*Epithelial Cells*—The epithelial cells lining the bronchial spaces, beyond the site of inoculation showed no necrosis or injury in any of the lesions as far as could be determined by the staining techniques employed. In some areas in the early lesions the epithelial lining of the bronchi became infiltrated with polymorphonuclear leucocytes, but there was no separation of the membrane from the bronchial walls. Proliferation and desquamation of individual epithelial cells were not seen. There was no phagocytosis of pneumococci by the epithelial cells, although in the early lesions large numbers of organisms were seen in the exudate covering their free surfaces.

*Alveolar Phagocytes*—The mononuclear cells which showed phagocytic activity presented a wide variety of sizes and ingested constituents depending on the age of the lesions. In the early lesions the old large pigment-filled macrophages were the only mononuclear cells which contained ingested pneumococci and red blood cells, although numerous small hematogenous mononuclear cells were present in the exudate. In the 12 and 15 hour lesions some of these smaller cells had taken up an occasional pneumococcus and red blood cell (Fig. 9). As these cells enlarged, their phagocytic activity increased so that many phagocytic mononuclear cells of varying sizes soon appeared in the exudate (Fig. 10).

In the 36 hour lesion the majority of the mononuclear phagocytic cells at or near the site of inoculation were larger than those seen in the 24 hour lesion, and filled with red blood cells, polymorphonuclear leucocytes and some pneumococci, showing various degrees of digestion (Fig 11). They were still larger in the 48 hour lesion and contained large numbers of ingested red blood cells and degenerating polymorphonuclear leucocytes (Fig 13). In the 3 to 4 day lesions the mononuclear phagocytes were somewhat larger than those seen in the 48 hour lesions and contained only fragments of ingested red blood cells and polymorphonuclear leucocytes (Fig 14). In these lesions the red blood cells and pneumococci and the majority of the polymorphonuclear leucocytes had disappeared from the exudate. In the 5 and 6 day lesions the mononuclear macrophages were all of the large variety and contained fat vacuoles and greenish pigment in their cytoplasm (Fig 15). They resembled in size the old pigment filled mononuclear cells seen in the early lesions, and also the attached septal cells. Similar mononuclear cells were seen in diminishing numbers in the exudate in resolving lesions (Fig 16).

In some areas in the pneumonic lungs, the macrophages, which left the alveoli during the course of resolution collected in the alveolar ducts at their junction with the respiratory bronchioles. Here they apparently transformed themselves into fibroblasts, elaborated connective tissue fibers to form connective tissue plugs, which became vascularized as a result of the ingrowth of capillaries from points along the surrounding walls (Fig 17). These connective tissue obstructions were composed essentially of large, pigment filled, phagocytic cells and were seen in small areas in the lungs of most of the animals killed from 10 days to 3 weeks after recovery. The lung tissue peripheral to or surrounding these obstructions showed no organization or general architectural alteration (Fig 18).

### *Reinfected Dogs*

The gross and microscopic findings in the lungs of the 10 reinfected dogs were in general similar to those seen in the animals receiving only one infection. The disease appeared to be less severe and the pneumonic process developed more rapidly than in the singly infected animals. The observations on the pathogenesis of lobar consolidation, the kinds of cells, and the sequence with which they appeared in the exudate, were similar to those seen in the animals receiving single infections. The mononuclear macrophages developed rapidly in the exudate and were derived principally from the small hematogenous mononuclear exudate cells which appeared early in the disease, as was seen in the lesions of the singly infected animals (Figs 19 to 22). The extent to which the local septal cells contributed to the alveolar phagocytes also could not accurately be determined in this series of reinfected animals. Some of the early lesions showed a moderate number of old, free pigment filled mononuclear cells, but these were considered to be residual cells from the previous infection. The pigment filled cells in the fibrous plugs which developed from the previous infection in some of the alveolar ducts did not appear to mobilize and enter the exudate during the course of the second infection.

## DISCUSSION

The cellular responses to the pneumococcus in these series of pneumonic lungs of dogs were similar to those described by Maximow (11, 12), Bloom (13), Tahaferro and coworkers (14, 15), Kolouch (16), and others in inflammation in general. These investigators found that the blood leucocytes constituted the chief source of the cells which appeared in the field of inflammation, and that the macrophages, which eventually replaced the polymorphonuclear leucocytes, were derived principally from the hematogenous mononuclear cells (lymphocytes and monocytes) after they entered the exudate. The inflammatory process in the lungs differed from that of their observations only in that the cellular exudate entered spaces not normally occupied by cells. Because of this, as well as the thinness of the alveolar septa, and the relative scarcity of cells on and in them, the migration of leucocytes through the capillaries could be easily seen in the freshly, intratracheally fixed preparations. The manner in which the leucocytes left the capillaries, forming asteroid configurations along the septa, was similar to the way they enter the air spaces during pneumonia in man, as shown by Ribbert (17) and Loosh (18).

Before and while the exudation of leucocytes took place, little change could be seen in the local tissue cells in the alveolar walls, bronchi, blood vessels, and pleura. The septal cells did not undergo desquamation as is frequently considered to occur early in pneumonia in man (19-23) and in experimental lesions in animals (24-27). Because they were not reduced in numbers on the walls by detachment in the early stages, their enlargement and increase in numbers in the later stages cannot represent a reparative process—a regeneration of the denuded lining of the alveolar spaces—as is generally taught. The septal cells, although they enlarged, remained as isolated cells. The alveolar surfaces between them remained smooth and showed no thickening or alteration to suggest that they were covered by cytoplasmic expansions of the septal cells.

It was difficult to determine if the changes in the septal cells represented a macrophage reaction as Robertson, Coggeshall, and Terrell (1) and Gunn and Nungester (28) concluded. As Robertson and coworkers observed, there was also no evidence, in this study, of phagocytic activity by the septal cells in any of the lesions. Morphological similarity between the septal cells and free mononuclear cells in the older lesions, however, would not seem to be sufficient evidence to classify the former as macrophages. There was little evidence also to indicate that the swollen cells became detached when the number of macrophages were increasing in the exudate, for mitotic figures, indicating proliferation, were rarely seen in them and then only in the later stages when binucleated cells began to appear on the septa. Some of the septal cells probably did become free to function as macrophages, but desquamation occurred slowly, for the macrophages diminished in the exudate as resolution progressed, although during this time the septal cells remained large and conspicuous on the

walls. The swelling and proliferation of the septal cells and other cellular constituents of the walls could be interpreted as a result of mild toxic injury due to the soluble products liberated by the pneumococci growing in the exudate and alteration in their environment as a result of consolidation.

In the exudate of animals killed after 48 hours, the mononuclear cells were chiefly of the typical macrophage variety, and one could readily get the impression that they were derived from the local swollen septal cells. On the other hand, by following the changes in the alveolar exudate from the beginning of the pneumonic process and at close intervals throughout its course, it was clear that they arose, in a large part, from smaller non-phagocytic, basophilic mononuclear cells of hematogenous origin. In the early lesions, the latter cells were morphologically indistinguishable from the lymphocytes of the blood, from which they could be seen entering the exudate along with the polymorphonuclear leucocytes. A few resembled monocytes. The hematogenous mononuclear exudate cells continued to migrate from the blood vessels throughout the period of consolidation. After they entered the exudate, it soon became impossible to separate them into groups as typical lymphocytes and monocytes, for they began to enlarge, assume many sizes, shapes, and transform themselves into phagocytic cells. During this process they became morphologically typical of "polyblasts" described by Maximow (11, 12) and showed increasing degrees of phagocytosis. The hypertrophy and transformation of lymphocytes into monocytes and monocytes into macrophages were more or less complete by the time the local cells began to be conspicuous on the walls. As there was no evidence of degeneration of the non-granular leucocytes after they entered the exudate, a sufficient number were present in the early stages to account for the majority of the large phagocytic mononuclear cells seen in the older lesions which also showed a swollen septal cell reaction.

As far as could be determined, the small non-phagocytic cells which transformed themselves into macrophages did not arise in the local connective tissue of the septal, bronchial, blood vessel, or pleural walls (29, 30), or from the endothelial lining cells of the alveolar capillaries as Permar (31) concluded. Small basophilic mononuclear cells, which resembled lymphocytes and plasma cells, increased in the interstitial tissue in the recovering lesions as the result of migration from the blood followed by local proliferation. Likewise, there was no evidence that large phagocytic mononuclear cells first developed in the interstitial tissue and then entered the exudate. The large pigment-filled mononuclear cells seen in the early lesions were present in the air spaces before the pneumonic process began. These cells are referred to by some as newly desquamated epithelial cells. Similar cells which increased in numbers in the interstitial tissue during resolution were indistinguishable from those still within the air spaces and are considered to be cells which had previously matured in and subsequently migrated from the exudate.

Fox (32) recognized that small round cells in the early pneumonic exudate in the lungs of man underwent pigmentary changes and increased in size Tchistovitch (33), studying the pneumonic process in dogs and rabbits, and Briscoe (34), during similar studies in guinea pigs, observed that the large mononuclear cells which became "powerful" phagocytes developed in the exudate from smaller non-phagocytic cells Tchistovitch concluded that these cells were of hematogenous origin Although Briscoe found it difficult to distinguish them from lymphocytes, he concluded that they arose from the alveolar epithelium The present study of pneumonia in the dog is in agreement with their findings, concerning the development of macrophages from smaller non-phagocytic cells within the exudate The gradual and progressive cellular changes which took place in the exudate indicate that the pneumonic process is a dynamic one This is further shown by the fact that the microscopic findings could be more closely correlated with the age of the lesions than with their gross appearance or the clinical condition of the animals at the time of death The inflammatory reaction in the case of pneumococcic pneumonia in man, most probably, is also a continuous dynamic process, although the usual description of the pathology does not give this conception This is because the microscopic pathology is usually described only in relation to the long recognized gross stages of congestion, red, and gray hepatization, and resolution, with each stage being given a definite, independent, cytological picture

In the current textbook discussions (21-23, 35, 36), and in the reports of the majority of those who have made special studies of the pathology of pneumonia in man (18, 30, 37, 38, 39), a wide variety of small non-phagocytic exudate cells of various sizes and shapes are described, assigned many names, and generally considered to be of hematogenous origin Although it is recognized that these cells disappear from the exudate in the later stages of the disease, a cytogenic relationship between them and the larger mononuclear phagocytic cells is usually not considered The latter cells are thought to be desquamated epithelial cells (20, 37) or histiocytes (29, 30, 40) which arise locally and enter the exudate at about the time resolution begins In view of the close similarity between the canine and human lesions, an analogous study of the cells in the exudate of the pneumonic process in man would probably reveal the same sequence of changes (18) that has been observed in this study The numerous "polyblastic" mononuclear cells which appear in the early stages would be found to represent transitional stages in the development of the hematogenous exudate cells into the larger phagocytic cells, and to be the chief sources of the latter This would also explain their disappearance from the exudate in the older lesions, an observation that puzzled Pratt (37) but, in general, one that is not commented upon Whatever the origin of the large mononuclear cells which eventually replace the polymorphonuclear leucocytes in the exudate, they become typical macrophages and serve an important function in overcoming the infection as shown by Robertson and Uhley (40)

Lymphatic, capillary, and vascular thromboses not infrequently described as part of the pathology of pneumococcic pneumonia in man (21, 37, 41, 42) were not observed in the freshly fixed lesions, although some of the animals were bacteremic when sacrificed. Megakaryocytes, similar to those described by Pratt in the lung capillaries of man, were also observed occasionally in the septal capillaries both in sections from consolidated and unconsolidated areas. There was no separation of the epithelium from the bronchial walls, and except for the small areas of trauma induced by the starch at the sites of inoculation, there was no necrosis or alteration in the general architecture of the lung parenchyma. The fibrous plugs occasionally observed in the alveolar ducts in the recovered lungs appeared to be the result of the transformation of the alveolar phagocytes into fibroblasts. The organization of the exudate only in the alveolar ducts and respiratory bronchioles without involving the surrounding lung parenchyma has not been, as far as can be ascertained, described in recovered pneumonic lungs in man.

The macroscopic observations on the development of pneumonic consolidation in these series of dogs are similar to those noted by Robertson, Coggeshall, and Terrell (1) during earlier studies of the disease in the same animal. However, microscopic examination revealed certain differences from their findings in respect to the distribution of pneumococci in the spreading lesion. While these authors describe the presence of pneumococci within the alveolar walls at an early stage of the inflammatory process, in the present study, organisms were not seen in the substance of the alveolar walls in areas within, at the margins of, or beyond the borders of the lesions. This discrepancy can be explained on the basis of the different techniques used in preparing the specimens for microscopic examination. Keeping the capillaries filled with the animal's blood and fixing the consolidated lungs intratracheally prevent collapse of the tissue, and one is able to visualize more clearly the alveolar walls and capillaries than when the specimens are simply immersed in the fixing solution. Large numbers of organisms were seen in the intratracheally fixed lungs, but they were invariably within the air spaces. Employing the special method of fixation used in this study, Robertson (43) has stated that his earlier interpretation that the pneumococci penetrated into the walls of the alveoli was incorrect.

In this study, pneumococcic pneumonia in the dog was from its earliest inception primarily an intraalveolar and intrabronchial infection. From the distribution of the pneumococci in the developing lesions it seemed most probable that they were spread throughout the air spaces as a result of the direct flow of the infected edema fluid from alveolus to alveolus through the pores of Kohn, and from bronchiole to bronchiole by aspiration during breathing and coughing. Gravity also appeared to play an important rôle in the direction of spread of the infection within the lobes. Injury to the lung tissues which resulted in exudation of the constituents of the blood into the air spaces was

brought about by the soluble toxic products liberated by the pneumococci growing within the exudate rather than by direct invasion of the septa by the organisms themselves. Spread of the organisms to the interstitial tissue was secondary to intraalveolar infection, and bore no relation to the extent or intensity of consolidation and, therefore, was not important in the mechanism by which consolidation was produced.

#### SUMMARY

The kinds of cells and the sequence in which they appeared in the inflammatory exudate were studied in a series of experimentally produced pneumonic lesions in dogs. There was a gradual and progressive change in the character of the exudate and the kinds of cells as the disease progressed. The microscopic findings could be more closely correlated with the age of the lesions than with their gross appearance or with the clinical condition of the animal at the time of death. The cells in the exudate came principally from the blood. The polymorphonuclear leucocytes were gradually replaced by larger phagocytic mononuclear cells. These were derived chiefly from the hypertrophy and transformation into larger phagocytic cells of the lymphocytes and monocytes of the blood after they entered the air spaces along with the polymorphonuclear leucocytes in the early stages of the disease. To follow the development of the hematogenous exudate cells into macrophages in the dog, the pneumonic process must be studied from its earliest inception and at close stages during the first 36 hours of the disease. The local septal cells contributed only in a minor way to the origin of the macrophages. Their principal reaction appeared to be one of enlargement without detachment from the alveolar walls. Consolidation of the lungs occurred as a result of the spread of the pneumococci through the air spaces by direct passage of the infected edema fluid from alveolus to alveolus through the pores of Kohn and from bronchiole to bronchiole from aspiration during breathing and coughing. The similarity of the histogenesis of the exudate cells in this series of experimentally induced pneumonic lesions in the dog and in those which occur spontaneously in man was discussed.

#### BIBLIOGRAPHY

- 1 Robertson, O. H., Coggeshall, L. T., and Terrell, E. E., *J. Clin. Inv.*, 1933, **12**, 433.
- 2 Robertson, O. H., Coggeshall, L. T., and Terrell, E. E., *J. Clin. Inv.*, 1933, **12**, 467.
- 3 Terrell, E. E., Robertson, O. H., and Coggeshall, L. T., *J. Clin. Inv.*, 1933, **12**, 393.
- 4 Robertson, O. H., and Fox, J. P., *J. Exp. Med.*, 1939, **69**, 229.
- 5 Loosli, C. G., *Arch. Path.*, 1937, **24**, 743.
- 6 Kohn, H. N., *Münch. med. Woch.*, 1893, **40**, 42.
- 7 Buchsbaum, R., and Loosli, C. G., *Methods of tissue culture in vitro and outlines of histological methods*, Chicago, The University of Chicago Press, 1936, 69.



- 8 Wallace, H M , *Science*, 1931, 74, 369
- 9 Coggeshall, L T , and Robertson, O H , *J Exp Med* , 1935, 61, 213
- 10 Lang, F J , *Arch exp Zellforsch* , 1926 2, 93
- 11 Maximow, A. A , *Beitr path Anat u allg Path* , 1929, 82, 1
- 12 Maximow, A. A., *Arch Path* 1927, 4, 557
- 13 Maximow, A A., and Bloom, W Textbook of histology, Philadelphia, W B Saunders Co , 3rd edition, 1938, 104
- 14 Taliaferro, W H , and Mulligan, H W , *Indian Med Research Mem* , 1937, No 29, 1
- 15 Taliaferro, W H , and Klüver, C , *J Infect Dis* , 1940, 67, 121
- 16 Kolouch, F , Jr, *Am. J Path* , 1939, 15, 413
- 17 Ribbert, H., *Virchows Arch path Anat* 1912, 209, 456
- 18 Loosli, C G , *J Lancet*, 1940, 60, 49
- 19 Armstrong R. R., and Gaskell, J F , *J Path and Bact* , 1921, 24, 369
- 20 Loeschcke, H , *Beitr path Anat u allg Path* , 1931, 86, 201
- 21 Heffron, R., *Pneumonia*, New York, The Commonwealth Fund 1939, 93
- 22 Karsner, H T , A textbook of pathology Philadelphia, J B Lippincott Co , 5th edition, 1938, 569
- 23 MacCallum, W G , A textbook of pathology Philadelphia, W B Saunders Co , 7th edition, 1940 531
- 24 Wadsworth, A *Am J Med Sc* , 1904 127, 851
- 25 Lamar, R. V , and Meltzer S J , *J Exp Med* , 1912 15, 133
- 26 Blake F G , and Cecil, R. L , *J Exp Med* 1920, 31, 445
- 27 Schöbl, O and Sellards, A. W , *Philippine J Sc* , 1926, 31, 1
- 28 Gunn, F D , and Nungester, W J , *Arch Path* , 1936, 21 813
- 29 Maschima, U , *Tr Jap Path Soc.*, 1920, 10, 171
- 30 Costa, A., *Sperimentale, Arch biol* , 1934, 68, 126
- 31 Permar, H. H *J Med Research*, 1923, 44, 27
- 32 Fox, W , Atlas of pathological anatomy of the lungs, London, J & A. Churchill, 1888, 15
- 33 Tchistovitch, N , *Ann Inst Pasteur*, 1890, 4, 285
- 34 Briscoe, J C , *J Path and Bact* , 1908, 12, 66
- 35 Oertel, H A., *Special pathology*, Montreal, Renouf Publishing Co , 1938, 231
- 36 Reimann H. A., *The pneumonias*, Philadelphia, W B Saunders Co , 1938, 41
- 37 Pratt, J H. *Johus Hopkins Hosp Rep* , 1900 9, 265
- 38 Heinrichs, H. *Virchows Arch. path Anat* , 1932, 284, 187
- 39 Evans, F A., *J Infect Dis* , 1916, 19, 440
- 40 Robertson, O H. and Uhley, C G , *J Clin Inv* 1936, 15, 115
- 41 Bezzola, D *Virchows Arch path Anat* , 1894, 138, 345
42. MacCallum, W G , The pathology of the pneumonia in the United States Army camps during the winter of 1917-18 Monograph of The Rockefeller Institute for Medical Research, No 10 New York, 1919
- 43 Robertson O H , *J Am Med Assn* 1938, 111, 1432

## EXPLANATION OF PLATES

Figs 1 to 5 photographed from a section stained with Wallace's modification of the Gram-Weigert technique. Figs 6 to 22 are photographed from sections stained with Maximow's hematoxylin-eosin-azure II stain.

## PLATE 22

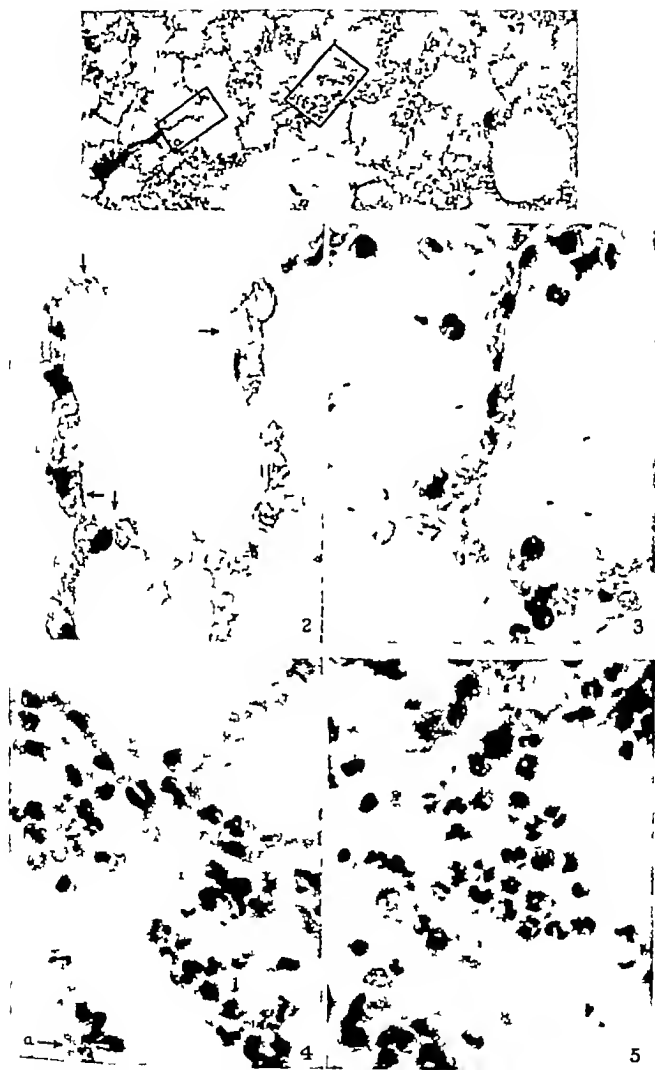
FIG 1 Dog 1-65T killed 36 hours after left lower lobe inoculation. The lobe was completely consolidated except for a small area at the posterior superior angle near the hilum. The photograph is of an area at the spreading border of lesion several centimeters from the site of inoculation. The alveoli contain principally edema fluid with only focal exudation of cells.  $\times 112$

FIG 2 Dog 1-65T. Beyond zone of edema-filled alveoli, the septal walls have a normal appearance and show only a thin layer of serous exudate on their surfaces. Pneumococci (arrows) are present in the exudate but not in the substance of the septa.  $\times 755$

FIG 3 Dog 1-65T. Area *a* in Fig 1 shows many pneumococci in edema-filled alveoli and none in the septal walls.  $\times 755$

FIG 4 Dog 1-65T. Area *b* in Fig 1 shows edema fluid, pneumococci, and leucocytes in alveoli. Many pneumococci have been ingested by the leucocytes. *a*, leucocytes are entering the alveoli from septal capillary.  $\times 757$

FIG 5 Dog 1-65T. An older area of involvement just to the right of that shown in Fig 1 nearer the site of inoculation shows no free pneumococci in the alveoli, but large numbers of leucocytes, filled with ingested organisms, are present. No pneumococci are seen in the substance of the alveolar walls.  $\times 755$



Figs 1 to 5  
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Maximow's ha

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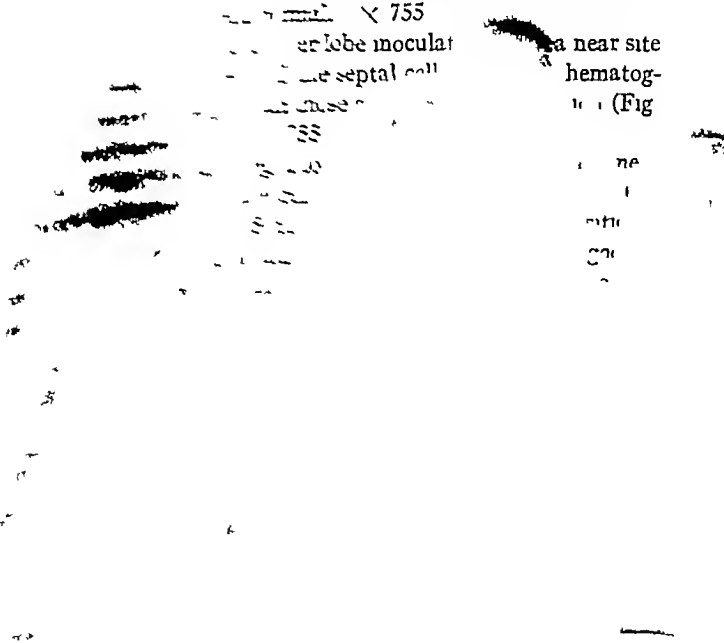
FIG 2 Dog  
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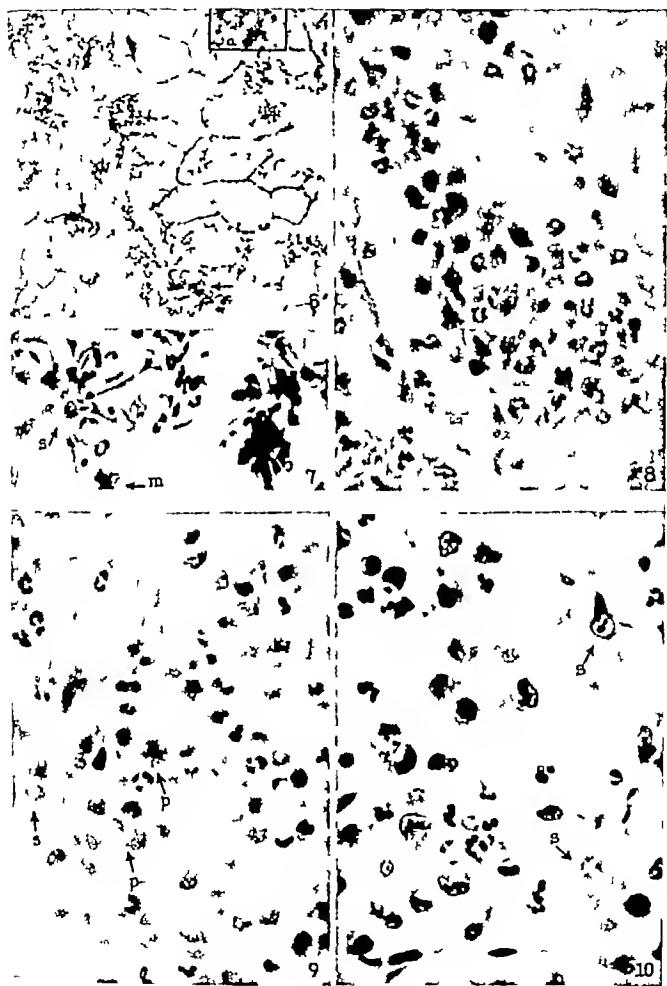
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FIG 4 Dog  
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FIG 5 Dog  
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... mononuclear exudate cells re-  
... X 755  
... after lobe inoculation  
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... a near site  
... hematog-  
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(Loosli Histogenesis of cells in pneumonia)

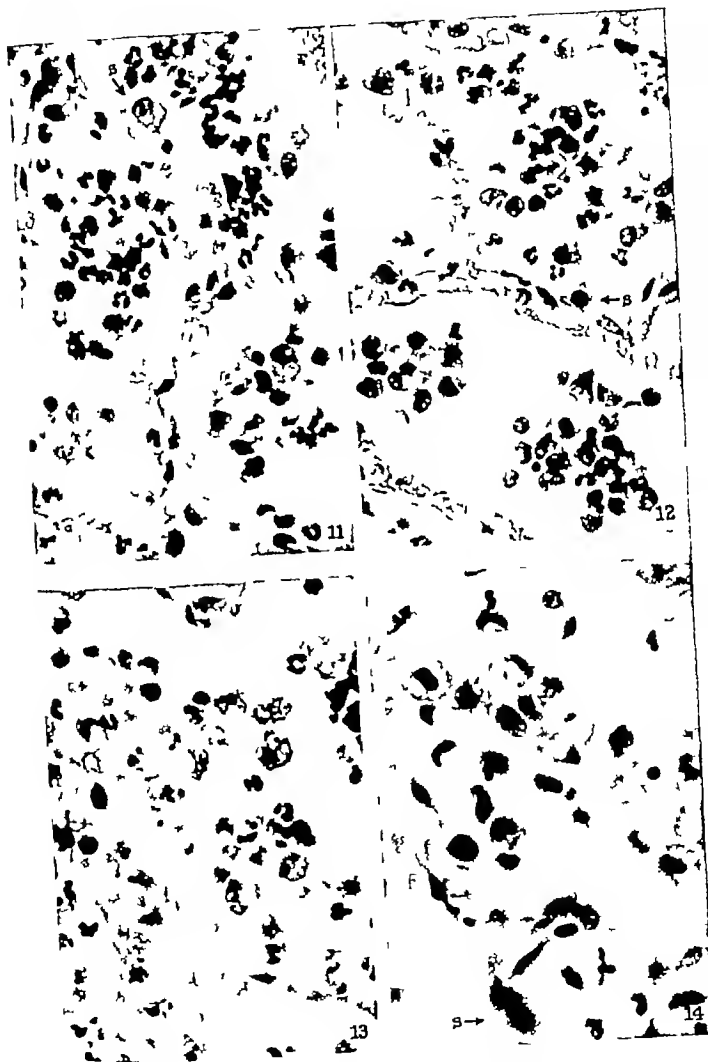
## PLATE 24

FIG 11 Dog 1-65T killed 36 hours after left lower lobe inoculation Area near site of inoculation shows still more large phagocytic mononuclear cells than were present at 24 hours (Fig 10) A few smaller mononuclear cells showing transitional stages in their development into macrophages are present The septal cells (*s*) are larger but no more numerous than they (*s*) are at the margin of the lesion (Fig 12) No pneumococci are seen  $\times 675$

FIG 12 Dog 1-65T A more recently involved area near the margin of the lesion, near that in Fig 5, shows numerous small deeply basophilic hematogenous mononuclear exudate cells of varying sizes and shapes The larger ones are phagocytic. Many of these cells resemble the lymphocytes and monocytes still within the blood vessels, as well as the mononuclear cells in the exudates of the earlier lesions (Figs 8 to 10) No large phagocytic mononuclear cells such as those seen near the site of inoculation are present  $\times 675$

FIG 13 Dog 1-70T killed 48 hours after left lower lobe inoculation The exudate near the site of inoculation consists principally of large actively phagocytic mononuclear cells Only a few smaller mononuclear cells are present The polymorphonuclear leucocytes are degenerating  $\times 755$

FIG 14 Dog 73R killed 72 hours after right lower lobe inoculation The exudate near the site of inoculation consists essentially of still larger mononuclear macrophages The alveolar walls appear normal except for the presence of isolated hypertrophied septal cells (*s*)  $\times 755$



## PLATE 25

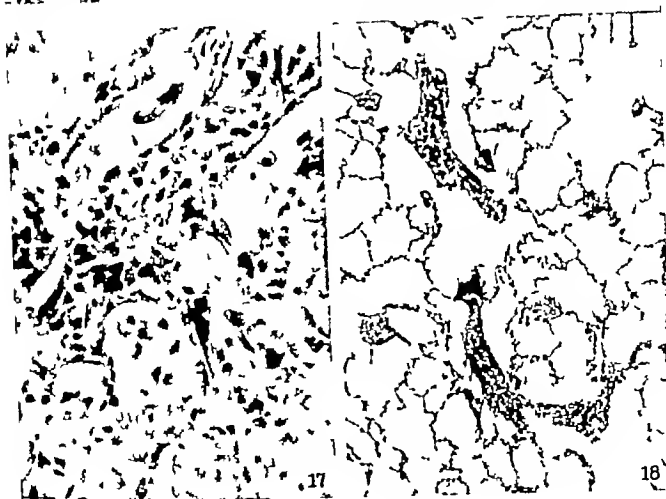
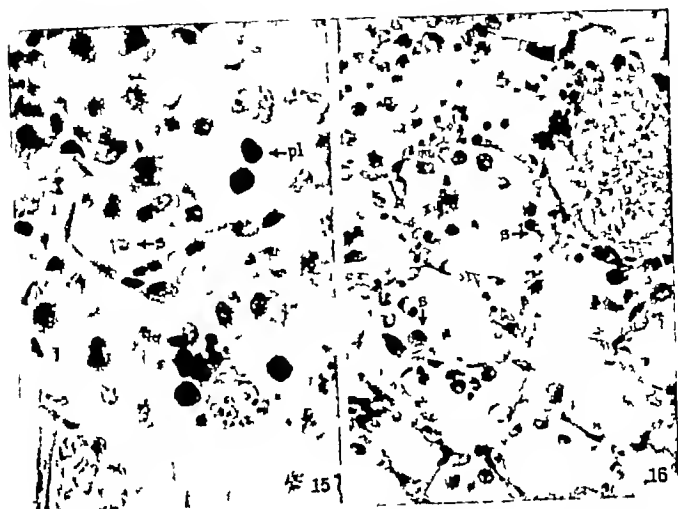
FIG 15 Dog 91N killed 6 days after right lower lobe inoculation Resolution has not yet begun in this area The majority of the large mononuclear macrophages contain pigment in their cytoplasm, and now resemble the pigment-filled macrophages which were occasionally seen in normal lungs The septal cells (s) are markedly swollen and resemble the free macrophages in size but contain no pigment in their cytoplasm A few plasma cells (pl) are present  $\times 675$

FIG 16 Dog 79R killed 5 days after right lower lobe inoculation Resolution is advanced Pigment-filled, mononuclear macrophages have decreased in numbers in the exudate The septal cells (s), however, are still large and conspicuous on the septal walls  $\times 375$

FIG 17 Dog 28P killed 10 days after right lower lobe inoculation Area shows a beginning organization of the macrophages which have collected in an alveolar duct  $\times 375$

FIG 18 Dog 35P killed 22 days after right lower lobe inoculation Resolution is complete, but obstructions in the alveolar ducts formed by organized collections of macrophages still persist They are attached to the walls by small strands of connective tissue The surrounding lung tissue appears normal  $\times 112$





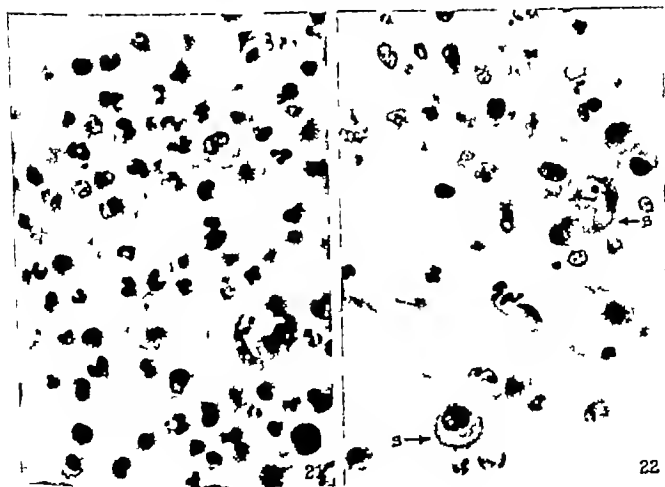
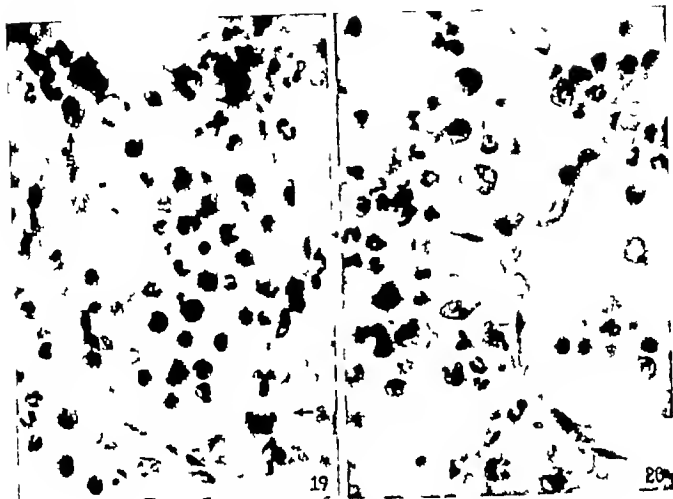
## PLATE 26

FIG 19 Dog 94N killed 12 hours after the second right lower lobe inoculation. The septal cells (s) are large, but the mononuclear exudate cells are small and many resemble lymphocytes. They are similar to the cells seen in the 8 hour (Fig 8) lesion of the dog receiving a single infection.  $\times 750$

FIG 20 Dog 87N killed 22 hours after the second right lower lobe inoculation. Mononuclear exudate cells are larger than those in the 15 hour (Fig 9) lesion.  $\times 750$

FIG 21 Dog 75R killed 32 hours after the second right lower lobe inoculation. The mononuclear exudate cells are of many sizes. The majority are larger than those seen in the 22 hour (Fig 20) lesion. The larger ones are actively phagocytic.  $\times 750$

FIG 22 Dog 86R killed 50 hours after the second right lower lobe inoculation. The mononuclear exudate cells are all of the large phagocytic variety. The two large deeply staining cells are recently detached septal cells (s).  $\times 750$





# THE EFFECTS OF RENAL HYPERTENSION ON THE VESSELS OF THE EARS OF RABBITS\*

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PLATES 27 AND 28

(Received for publication, February 5, 1942)

Evidence that peripheral arterioles are constricted in arterial hypertension of renal origin has been adduced either from results of studies made by indirect methods or from direct observation of the small arteries in the ocular fundi. Both sources of information leave much to be desired, therefore, the application of a more precise and direct technique to the study of the problem seemed necessary. It consists of direct observation with the microscope before and after induction of renal hypertension of innervated and non innervated arterioles and of veins and capillaries which have grown into a transparent chamber placed in the ear of a rabbit. Since the vessels and their contents can be seen with great clarity, minute changes can be recognized when they occur.

It was our desire to ascertain with certainty whether persistent arteriolar constriction occurred when hypertension was produced and whether the constriction was of such a degree that reduction of blood flow to the tissues did not occur. This was the picture to be expected from observations made (Abell and Page, 1940) during the acute hypertension produced by intravenous injection of angiotonin (Page and Helmer, 1939). Further, the question as to whether arteriovenous shunts open when hypertension occurs is an important one to answer because of the wide use of thermometric and plethysmographic methods for the study of this same problem. Indeed, using these methods diametrically opposed results have been obtained with regard to the blood flow in the extremities of hypertensive patients when compared with normal persons (Prinzmetal and Wilson, 1936, Pickering, 1936, Abramson and Fierst, 1942).

## Methods

The methods employed in this investigation were similar to those recently reported by Abell and Page (1942). Essentially they consisted of examining, photographing,

\* Brief reference to some of the results reported in this paper was made by the authors at the General Scientific Meeting at the Marine Biological Laboratory Woods Hole, Massachusetts, August 26 1941 (Abell, R. G. and Page, I. H., *Biol. Bull.*, 1941, 81, 293).

Before and after induction of renal hypertension, blood vessels which were in the snout chamber (Abell and Clark, 1932, Abell, 1937). In some of the arterioles did not constrict spontaneously indicating that they were not supplied with nerves. The arteriole in one rabbit's ear constricted throughout only part of its length, suggesting that the nerve was not intact (Clark, Clark, and Williams, 1934). The arterioles studied were of from 29 to 84  $\mu$ m.

The rabbits were made hypertensive either by constricting the renal artery with a silver clip (Goldblatt, Lynch, Hanzal, and Summerville, 1934) and removing the opposite kidney, or by wrapping one kidney in silk and removing its partner kidney. Arterial blood pressure was determined in 8 of the 10 rabbits with the apparatus of Moberg (1934). The absolute values determined are incorrect but relative values reasonably reliable.

Ten chambers were used, each one being in the ear of a different rabbit.

#### Observations

Arteriovenous anastomoses may normally be present in transparent chambers (Clark and Clark, 1934). Such anastomoses were observed rarely in normotensive and commonly in hypertensive rabbits in these experiments. Fifty moat chambers in the ears of normotensive rabbits failed to show more than a few of them. In those in which they occurred the number was usually limited to one or two and there were never more than eight. But in the hypertensive rabbits, not only were more present but more blood passed through such connections than in the normotensives. For example, repeated observations showed no anastomoses in the chamber of rabbit 6 before development

TABLE I

*The Effect of Induction of Hypertension on the Diameter of the Arterioles in Rabbits' Ears*

Rabbit No.		Blood pressure	Diameters of arterioles A B C		
			A	B	C
			microns	microns	microns
1	Control				
	Day before operation	Normal	77	84	21
	Hypertensive				
	7 days after operation	2.1 × normal	52	49	14
4	Control				
	Day before operation	Normal	77-35	56-28	35-21
	Hypertensive				
	4 days after operation	1.5 × normal	24-21	19-17	14-13
6	Control				
	Day before operation	Normal	35	35	29
	Hypertensive				
	2 days after operation	1.7 × normal	19	14	14
10	Control				
	3 days before operation	Normal	80		
	Hypertensive				
	23 days after operation	1.5 × normal	60-40		

of hypertension but after it, 15 appeared. None were seen in rabbits 1 and 4, five and six, respectively, appeared after induction of hypertension.

How long such newly formed anastomoses persisted and remained functional in the hypertensive animals was not determined. In one chamber, however, all of the newly formed anastomoses were studied daily for 7 days, during which time they continued to be active.

The blood corpuscles in the capillaries and venules, and the flow of blood through the vessels could be very clearly seen. No change was observed in the appearance of the erythrocytes, and the movements of the corpuscles gave no indication of any change in viscosity of the blood following the development of hypertension.

and measuring, before and after induction of renal hypertension, blood vessels which had grown into the moat chamber (Abell and Clark, 1932, Abell, 1937) In some of the chambers the arterioles did not constrict spontaneously indicating that they probably were not supplied with nerves The arteriole in one rabbit's ear constricted spontaneously throughout only part of its length, suggesting that the nerve had grown only that far (Clark, Clark, and Williams, 1934) The arterioles studied had normal diameters of from 29 to 84  $\mu$ m

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Ten chambers were used, each one being in the ear of a different rabbit

### *Observations*

When the rabbits became hypertensive (4 experiments) the arterioles constricted to 0.4 to 0.7 of their control diameters (Table I) The blood flow was not interrupted, but the degree of constriction was probably sufficiently great to increase the resistance to it Photographs of the blood vessels before and after the animals became hypertensive are shown in Figs 3 to 9 and in Figs 10 to 13, 16, and 17 If after operation the rabbits did not become hypertensive, arteriolar constriction did not occur (Figs 1 and 2)

The constriction in the hypertensive rabbits was due to active muscular contraction, and was not passive This is shown by the increased thickness of the walls of the constricted arterioles, seen both directly with the microscope, and in the photographic records (*cf* especially Fig 11) Arterioles which constricted spontaneously in normal rabbits showed constriction of greater degree when the rabbits became hypertensive (Figs 7 to 9) No constriction of any capillaries was observed Some of the larger veins in the chambers were narrower following the development of hypertension than they were when the pressure was normal Further experiments are needed, however, before it can be determined whether such narrowing was due to constriction, or to a general remodeling of the venous plexus such as occurs in transparent chambers in normal rabbits (Clark, Hitschler, Kirby-Smith, Rev, and Smith, 1931)

Small hemorrhages from the blood capillaries occurred 6 to 14 days respectively after the onset of hypertension in two animals (rabbits 1 and 6) This was 6 and 11 days after the arterial pressure had reached twice its normal level Sticking of leukocytes to the walls of the capillaries and venules increased from the normal condition of phase 1 to phase 4 of the Clark and Clark (1935) scale, and active emigration was observed In some places, leukocytes stuck to the walls of the venules in clumps which broke away at times, and floated off in the blood stream



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	Day before operation	Normal	35	35	29
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	2 days after operation	1.7 $\times$ normal	19	14	14
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	3 days before operation	Normal	80		
	Hypertensive				
	23 days after operation	1.5 $\times$ normal	60-40		

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The arteriolar constriction that occurs in transparent chambers upon development of hypertension resembles that caused in normal rabbits by intravenous injections of angiotonin, as described by Abell and Page (1940, 1942). This was shown in the present experiments by injecting angiotonin in amounts varying from 0.2 to 2.0 cc into each of 6 rabbits, and measuring the extent of arteriolar constriction. After the arterioles had returned to their normal diameters, the rabbits were operated upon and the constriction measured in the 4 that became hypertensive. Following injections of angiotonin, the arterioles constricted from normal to about 0.4 to 0.8 their original

TABLE II

*Diameters of Two Arterioles in Each of Three Different Moot Chambers Showing (1) Control Diameters of the Arterioles When the Rabbits Were Normotensive, (2) Diameters of the Same Arterioles in the Normotensive Rabbits at the Time of Greatest Constriction Following the Intravenous Injection of Angiotonin, and (3) Diameters of the Same Arterioles after the Rabbits Had Become Hypertensive*

Designation of arterioles studied	Control diameter rabbits normotensive	Diameters of the arterioles in normotensive rabbits at time of greatest constriction following injection of angiotonin	Amount of angiotonin injected	Diameters of the same arterioles when the rabbits became hypertensive	Degree of increase in blood pressure upon development of hypertension
	microns	microns	cc	microns	
		Rabbit 1			
A	77	53	1.0	52	2.1 $\times$ normal
B	21	14	1.0	14	2.1 $\times$ normal
		Rabbit 4			
A	28	13	0.2	15	1.5 $\times$ normal
B	20	10	0.2	12	1.5 $\times$ normal
		Rabbit 6			
A	35	21	0.2	19	1.7 $\times$ normal
B	35	20	0.2	14	1.7 $\times$ normal

diameters. Induction of hypertension causes vasoconstriction of about the same degree, as illustrated in Table II. In 10 normotensive animals 30 injections of angiotonin were given. Photographs of arterioles before and after the injection of angiotonin, and of the same arterioles before and after development of hypertension are shown in Figs. 14 to 17.

#### DISCUSSION

The present experiments show by *direct observation* that peripheral arteriolar constriction occurs in the ears of rabbits during experimental renal hypertension.

It should be emphasized that these studies have been made on vessels in rabbit's ears in which the arterioles normally show a high degree of activity

in dilating and constricting, consequently, conclusions drawn from the *extent* of constriction found here should not be applied to other peripheral arterioles without further study. Such studies are at present in progress.

It was shown by Abell and Page (1941, 1942) that intravenous injections of both renin and angiotonin cause arteriolar constriction, but that injections even of large amounts failed to produce constriction of sufficient degree to interrupt blood flow. This is of interest in view of the present observations that peripheral arteriolar constriction in hypertensive animals also does not interrupt the blood flow. The fact that the arterioles constricted to approximately the same degree following injections of angiotonin as following the development of hypertension (Page, 1941) is in accord with the evidence that hypertension, as produced in these experiments, is due to release of renin by the kidneys and the consequent formation of angiotonin within the blood stream.

Constriction of newly formed arterioles which had probably never been supplied with nerves occurred in the hypertensive rabbits, suggesting that the substance responsible for the hypertension acts directly upon the smooth muscle of the arterioles. This is true of angiotonin. Evidence from a wide variety of experiments has demonstrated that the nervous system is not necessary for the genesis of experimental renal hypertension (Page, 1940).

It might be suggested that secondary contraction of connective tissue is in some measure responsible for the narrowing of the vessels, though there is no evidence that this is true. Had it been true, marked constriction of the veins as well as the arterioles should have occurred. Furthermore, no change in the diameter of the capillaries or the position of the vessels in the chamber was observed, as might have been anticipated had generalized contraction of the connective tissue occurred. The constriction of the arterioles was due to smooth muscle contraction as shown by thickening of the smooth muscle cells in the walls of the arterioles.

Clark and Clark (1934) showed that stimuli which cause a sudden increase in circulation followed by the prolonged maintenance of an increased blood flow may lead to the formation of numerous arteriovenous anastomoses in a previously stable vascular network. It is of interest to note that arteriovenous anastomoses developed in the present experiments when the arterial pressure increased. The anatomical basis for formation of them is present in the primitive arterial venous capillary connections while the immediate stimulus to their formation lies in the rather suddenly increased blood flow. It is not surprising that more blood should go through such connections under conditions of increased arterial pressure.

Dr R. G. Williams permits us to state that, following intravascular injections of methylene blue into rabbits' ears, certain preparations showed selective staining of smooth muscle cells which were found to be present on the

walls of some of the veins. Such veins might show constriction in hypertension.

Intravenous injections of large amounts of renin and angiotonin caused slight constriction of some of the veins in moat chambers. The degree of constriction was not as great as that of the arterioles. Constriction of veins of 0.2 to 0.6 mm diameter in response to intravenous injections of epinephrine, ephedrine, and ergotoxin was observed by Wilson (1936) in preformed tissue chambers in rabbits' ears. Most of the veins in moat chambers do not exceed 0.1 mm in diameter.

The absence of capillary constriction in hypertension is to be expected if the renin-angiotonin vasopressor system is involved, since it has been shown by Abell and Page (1940) that intravenous injections of renin and angiotonin do not cause capillary constriction.

#### SUMMARY

1 The present experiments demonstrate by direct observation that peripheral arterioles in moat chambers in rabbits' ears constrict during the development of renal hypertension, and that they remain persistently constricted, although not sufficiently to interrupt the blood supply to the tissues. The arteriolar constriction in the hypertensive animals was not dependent upon nerves, since it occurred in newly formed arterioles which had probably never been supplied with nerves, as well as in older arterioles with a functional nerve supply.

2 No capillary constriction was observed during or following the development of hypertension, although the walls of the capillaries could be very clearly seen. Persistent hypertension was associated in two examples with increased sticking of leukocytes to the walls of the capillaries and venules, some emigration of leukocytes, and a few small hemorrhages.

3 During development of hypertension, new arteriovenous anastomoses were observed to appear in the chambers.

4 No evidence of change was noted in the viscosity of the blood or in the appearance of the blood corpuscles in the hypertensive rabbits.

5 The constriction of the arterioles during and following the development of hypertension closely resembled that produced by intravenous injections of angiotonin.

#### CONCLUSIONS

Experimental renal hypertension in rabbits causes persistent, visible constriction to occur in the arterioles of the ears which is not great enough to restrict the flow of blood to the tissues but is sufficient to increase peripheral resistance. The constriction is due to the direct action of a substance on the arterioles since it occurs in the absence of nerves to vessels. It is associated

with the appearance of new arteriovenous anastomoses. Since many of these phenomena have been reproduced by injection of angiotonin, this evidence is consonant with the view that the hypertension is due to angiotonin or some similar substance.

The authors wish to express appreciation to Mr. Harold Worth and Mr. B. B. Varian for assistance with the photomicrographs and to Dr. K. K. Chen and Mr. R. Parker for aid in the prosecution of the experiments.

#### BIBLIOGRAPHY

1. Abell, R. G., *Anat. Rec.*, 1937, 69, 11.
2. Abell, R. G., and Clark, E. R., *Anat. Rec.*, 1932, 53, 121.
3. Abell, R. G., and Page, I. H., *Biol. Bull.*, 1940, 79, 357.
4. Abell, R. G., and Page, I. H., *J. Exp. Med.*, 1942, 75, 305.
5. Abramson, D. I., and Fierst, S. M., *Am. Heart J.*, 1942, 23, 84.
6. Clark, E. R., and Clark, E. L., *Am. J. Anat.*, 1934, 54, 229.
7. Clark, E. R., and Clark, E. L., *Am. J. Anat.*, 1934, 55, 407.
8. Clark, E. R., and Clark, E. L., *Am. J. Anat.*, 1935, 57, 385.
9. Clark, E. R., Clark, E. L., and Williams, R. G., *Am. J. Anat.*, 1934, 55, 47.
10. Clark, E. R., Hirschler, W. J., Kirby-Smith, H. T., Rex, R. O., and Smith, J. R., *Anat. Rec.*, 1931, 50, 129.
11. Goldblatt, H., Lynch, J. R., Hanzal, R. F., and Summerville, W. W., *J. Exp. Med.*, 1934, 59, 347.
12. Moberg, E., *Skand. Arch. Physiol.*, 1934, 69, 218.
13. Page, I. H., *Science*, 1939, 89, 273.
14. Page, I. H., *Blood, heart and circulation in Newer aspects of experimental hypertension*. The American Association for the Advancement of Science, 1940, No. 13, 239.
15. Page, I. H., *Am. J. Physiol.*, 1941, 134, 789.
16. Page, I. H., and Helmer, O. M., *Proc. Centr. Soc. Clin. Research*, 1939, 12, 17.
17. Pickering, G. W., *Clin. Sc.*, 1936, 2, 209.
18. Prinzmetal, M., and Wilson, C., *J. Clin. Inv.*, 1936, 15, 63.
19. Wilson, H. C., *J. Pharmacol. and Exp. Therap.*, 1936, 58, 97.

## EXPLANATION OF PLATES

## PLATE 27

Photomicrographs of blood vessels in moat chambers The blur within the vessels indicates blood flow The direction of flow is shown by the arrows A, arteriole, V, venule Magnification  $\times 168$

FIG 1 Vessels in rabbit 5, 3 days before operation This shows control diameters of the vessels

FIG 2 The same vessels as in Fig 1, 8 days after the removal of one kidney The rabbit did not become hypertensive, the arterioles did not constrict The change in diameter of the the venule is due to normal remodeling of the venous plexus within the chamber

FIG 3 Vessels in rabbit 6, 1 day before operation, showing control diameters

FIG 4 The same field as in Fig 3, 2 days after the operation The arterial pressure is 1.7 normal, the arterioles are constricted

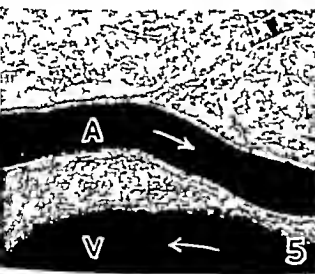
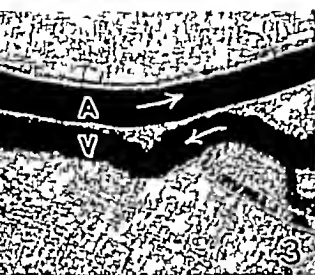
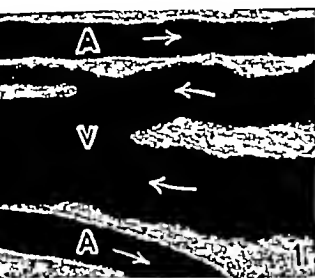
FIG 5 Vessels in rabbit 1, 1 day before operation, showing control diameters

FIG 6 The same vessels as in Fig 5, 5 days after the operation The blood pressure is 1.7 normal, the arterioles are constricted

FIG 7 Blood vessels in rabbit 4, showing the narrowest diameter reached by an arteriole that contracted spontaneously The blood pressure is normal (control photograph)

FIG 8 The same field as above, showing the least diameter reached by the arteriole under conditions of normal blood pressure (control photograph)

FIG 9 The same field 5 days after the operation The blood pressure is 1.5 normal, the arteriole is constricted beyond its narrowest normal limit



## PLATE 28

Photomicrographs of blood vessels in moat chambers Figs 10, 12, 14, and 16 show the vessels in normotensive rabbits Figs 11, 13, and 17 show the vessels after the rabbits became hypertensive Magnification  $\times 337$

FIG 10 An arteriole and venule in rabbit 1, 1 day before operation, showing control diameters of the vessels

FIG 11 The same field 5 days after the operation The arterial pressure is 17 normal, the arteriole is constricted The increase in thickness of the wall of the arteriole is due to smooth muscle contraction

FIG 12 Blood vessels in rabbit 6, 1 day before operation, showing normal diameters of the vessels

FIG 13 The same field 2 days after the operation The arterial pressure is 17 normal, the arterioles are constricted

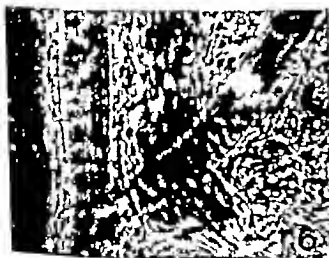
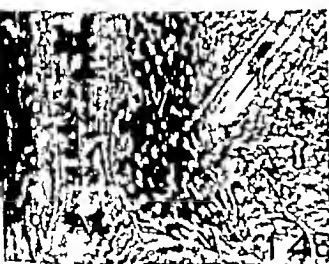
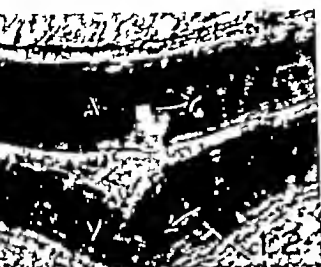
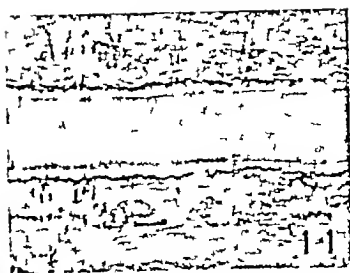
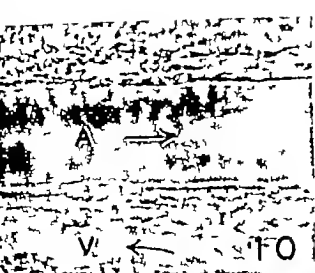
FIG 14 A branching arteriole and a venule in rabbit 4 The vessels are normal

FIG 15 The same field as in Fig 14, 12 minutes following the intravenous injection of 0.2 cc angiotonin, showing the greatest degree of constriction produced by the angiotonin The arteriole returned to its normal diameter within 7 minutes after the injection

FIG 16 The same field 1 day after the injection of angiotonin, showing the normal diameter of the vessels. This photograph was taken 5 hours and 30 minutes before the operation

FIG 17 The same field 5 days after the operation The arterial pressure is 15 normal, the arteriole is constricted The degree of constriction is approximately the same as that which occurred following injection of the 0.2 cc angiotonin







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